

AD-A258 473

AL-TR-1992-0134



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AUTOMATIC INFORMATION PROCESSING AND HIGH PERFORMANCE SKILLS

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OCTOBER 1992

FINAL TECHNICAL REPORT FOR PERIOD AUGUST 1988 - JUNE 1992

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Logistics Research Division

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 1992	3. REPORT TYPE AND DATES COVERED Final - August 1988 to June 1992		
4. TITLE AND SUBTITLE Automatic Information Processing and High Performance Skills		5. FUNDING NUMBERS C - F33615-88-C-0015 PE - 61101F PR - ILIR TA - 40 WU - 01		
6. AUTHOR(S) F. Thomas Eggemeier Arthur D. Fisk		8. PERFORMING ORGANIZATION REPORT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <div style="display: flex; justify-content: space-between;"> <div>University of Dayton Research Institute 300 College Park Drive Dayton, OH 45469</div> <div>Georgia Institute of Technology School of Psychology Atlanta, GA 30332-0170</div> </div>		10. SPONSORING / MONITORING AGENCY REPORT NUMBER AL-TR-1992-0134		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Armstrong Laboratory Human Resources Directorate Logistics Research Division Wright-Patterson AFB, OH 45433-6573		11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Beverly Gable, AL/HRGA, WPAFB OH, (513) 255-7773		
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) This document summarizes a three-year research effort which investigated automatic processing theory and high performance skills training. Issues pertaining to skill acquisition, transfer for training, skill retention, and operator workload were investigated with a variety of search and decision making tasks which were intended to represent laboratory analogs of some Command and Control (C2) operator functions. The results of this work indicate that automatic processing can be developed with training in C2 task analogs, and suggest some conditions and limits on both the acquisition and transfer of automatic processing under conditions that are expected to be encountered within C2 systems. The results also indicate that there is minimal loss of automatic processing over retention intervals of up to one year, and demonstrate that the workload associated with task performance is reduced under automatic processing conditions. Performance principles and training guidelines that are based on the results of this effort are presented.				
14. AUTOMATIC TERMS Automatic Processing Command and Control Controlled Processing Decision Making		High Performance Skills Part-Task Training Retention Skill Acquisition		15. NUMBER OF PAGES 145
		Training Transfer of Training Visual Search Workload		16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR	

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PREFACE

The work documented in this report was conducted under Air Force Armstrong Laboratory Contract No. F33615-88-C-0015 with the University of Dayton Research Institute. This work supported an integrated research program with the objective of developing advanced part-task training techniques based on information processing theory. Dr. Beverley A. Gable served as the Armstrong Laboratory, Logistics Research Division, Wright-Patterson Air Force Base, contract monitor.

The authors of this report are listed alphabetically. The report represents equal contributions by both authors. Mr. Gregory L. Brake provided valuable assistance in preparation of the report.

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I. INTRODUCTION

Automatic Processing and High Performance Skills

Air Force Command and Control (C²) systems require the human operator to rapidly and accurately process large volumes of information. These systems can impose multiple information processing demands on the operator in the form of cognitive functions (e.g., decision making, information retrieval) that must be performed concurrently and through the requirement to sample and integrate information from a number of input channels. Thus, efficient operation of C² systems requires highly skilled personnel who are capable of performing under high workload or timesharing conditions. The high-performance skills demanded of operators typically require extensive practice to develop and are characterized by qualitative differences between the novice and expert (Schneider, 1985).

The increases in speed, accuracy, and timesharing proficiency that can occur with extensive training have led to the development of an automatic/controlled theory of information processing (e.g., Fisk, Ackerman, and Schneider, 1987; Logan, 1985; Schneider, Dumais, and Shiffrin, 1984; Schneider and Shiffrin, 1977; Shiffrin, 1988; Shiffrin and Schneider, 1977). According to this theory, automatic processing represents a rapid, parallel, and effortless process that is not subject to the capacity or resource limits usually associated with operator performance. By contrast, controlled processing is a relatively slow, effortful, sequential process that is resource/capacity limited. Automatic processing develops with extended practice under consistently mapped (CM) conditions in which there is a consistent relationship between task components (e.g., a stimulus and the required response). Controlled processing is typically associated either with novel tasks or variably mapped (VM) conditions in which task component relationships vary from situation to situation.

Within the automatic/controlled processing theory framework, automatic processes represent important components of skilled operator performance. Certain elements of skill can result from the automatization of CM task components; this contributes to the speed and efficiency of expert performance. However, most complex skills involve some combination of both controlled and automatic processing (Logan, 1985; Schneider et al., 1984; Shiffrin and Dumais, 1981).

Because of the efficiency that characterizes automatic processes, this mode of processing is of substantial potential importance to Air Force C² operator performance. As indicated earlier, automatic tasks or task components are performed more rapidly and accurately than controlled tasks/components (e.g., Eggemeier, Adapathya, Elvers, Cooper, Summers, Biers, Rogus, and Prokop, 1992; Eggemeier, Bower, Granitz, Rogus, Mitchell, and Vukelic, 1991; Eggemeier, Granitz, Rogus, and Geiselman, 1990; Fisk, Hodge, Lee, and Rogers, 1990; Fisk, Hodge, Rogers, Lee, Hertzog, and Corso, 1992; Fisk, Rogers, Lee, Hodge, and Whaley, 1991; Fisk and Schneider, 1983; Hale and Eggemeier, 1990; Myers and Fisk, 1987). Automatic processes can also result in less variable performance than controlled processes (e.g., Eggemeier et al., 1991; Myers and Fisk, 1987).

In addition to increased speed and accuracy and decreased variability of performance, important potential benefits of automatic processing within C² system operation include reduced operator workload and improved timesharing efficiency. Improved timesharing efficiency can be of substantial importance because of the high workload imposed by C² systems. This efficiency can result from reduction in the information processing capacity/resource expenditure which is associated with the performance of CM components of complex skills. Reduction of the processing requirements associated with CM task components can free up processing resources for application to other tasks or

components, resulting in the potential for improved performance and timesharing efficiency. The high levels of timesharing efficiency that can be associated with automatic processing have been demonstrated in a number of studies in which automatized tasks have been efficiently performed with concurrent controlled tasks (e.g., Fisk and Lloyd, 1988; Fisk and Schneider, 1983; Logan, 1978, 1979; Schneider and Fisk, 1982a, 1984; Strayer and Kramer, 1990; Venturino, 1991).

Implications of Automatic/Controlled Processing Theory for Training

The distinction drawn by automatic/controlled processing theory between CM and VM task components has important implications for training programs designed to support automatic processing development within elements of complex tasks. Only CM task components can be automatized; therefore, the theory suggests that training programs should be structured to provide extensive practice of these elements. Part-task training, which permits practice to be focused on critical CM components, represents one viable means of providing the required training (e.g., Eggemeier, Fisk, Robbins, Lawless, and Spaeth, 1988; Schneider, Vidulich, and Yeh, 1982). A part-task training approach to establishing automatic processing in selected task components requires the identification of the CM elements of operator tasks through task analytic procedures and the inclusion of these components in training devices to provide the requisite training. Eventually, CM task components trained in this manner would have to be integrated into the total task through full simulation or other whole-task training techniques.

Automatic processing development in components of selected skills represents a potentially important aspect of an overall approach to C² operator training. The present literature concerning automatic processing and its characteristics is quite

extensive (e.g., Fisk et al., 1987; Neumann, 1984; Schneider et al., 1984; Shiffrin, 1988; Shiffrin and Dumais, 1981). However, evaluating the viability of a part-task training approach intended to support automatic processing development within components of C² operator tasks requires extension and refinement of the present data base in a number of important areas. Each area is important from the standpoint of either supporting the design of part-task training programs or determining the characteristics of automatic processing under conditions that approximate those which are likely to be found in C² systems. Extension and refinement of the current data base within four areas are critical to C² operator performance and training. These areas include: (1) the conditions that permit or facilitate automatic processing development within tasks (e.g., memory search, memory/visual search) and with classes of information (e.g., semantic category information, spatial pattern information) that represent those found within C² systems, (2) transfer of training functions under conditions that are of potential importance to C² training program development, (3) retention functions associated with automatic processing of information typical of that found in C² systems, and (4) the workload associated with automatic versus controlled processing in tasks representative of C² processing functions.

This report summarizes the results of a three-year research effort that addressed each of the four areas noted above. Detailed treatment of the methodology and results of each experiment conducted under this program can be found in a series of previously published technical reports and papers (Eggemeier et al., 1990, 1991, 1992; Fisk et al., 1990, 1991, 1992) that document each phase of the effort. The objective of this report is to provide an integrated summary of work conducted under the program. Each of the following four sections (II through V) is devoted to one of the major areas investigated. Section VI presents a set of augmented information processing principles and training guidelines that are based on the results

of the present effort and the current automatic processing literature. These principles and guidelines incorporate information that should prove useful in supporting the design of training programs intended to permit automatic processing development within consistent components of operator skills.

II. ACQUISITION OF AUTOMATIC PROCESSING AND SKILLED PERFORMANCE

Development of Automatic Processing in Tasks Requiring the Processing of Spatial Pattern Information and Complex Alphanumeric Information

Air Force C² systems, such as air weapons control and event detection, require the operator to rapidly and accurately process a variety of spatial pattern and complex alphanumeric information under high workload conditions (Eggemeier et al., 1988). This information differs in both type and complexity from the relatively simple alphanumeric materials (e.g., individual numerals or letters of the alphabet) used in much of the initial laboratory work that provided the basis of automatic/controlled processing theory (see Schneider et al., 1984). Therefore, information from these earlier studies may not be directly applicable to training operator task components that require spatial and complex alphanumeric materials.

The objective of the experiments described in this section was to investigate automatic processing development in memory and memory/visual search tasks requiring the processing of spatial pattern and complex alphanumeric information analogous to that in the noted Air Force C² systems.

Automatic Processing of Spatial Pattern Information

The first set of experiments in this series addressed the automatic processing of spatial pattern information. As described above, Air Force C² systems such as air weapons control

and event detection require the operator to process large amounts of spatial pattern information. These spatial patterns portray the presence and movement of certain targets (e.g., aircraft) on system displays (Eggemeier et al., 1988). System displays in air weapons control systems, for example, require the operator to monitor the radar returns associated with controlled aircraft and detect changes in the speed and/or direction of movement through associated changes in the spatial patterns.

One important characteristic of controlled aircraft is acceleration. This variable is portrayed by progressive increases in the distance between successive returns on the display. Changes in course are depicted by changes in the direction of movement of successive returns on the display. Although spatial pattern information is essential to operator performance within such systems, relatively little work has been performed to investigate automatic processing of such information.

Previous work with automatic processing of spatial pattern information (e.g., Eberts and Schneider, 1986; Schneider, et al., 1982) produced somewhat mixed results regarding the capability of subjects to fully automatize the processing of such information. Eberts and Schneider (1986), for example, reported several studies concerning the effect of extensive practice on the detection of line segment patterns. These patterns consisted of individual elements presented sequentially on channels of a visual display. Both CM and VM conditions were included in the experiments. The results demonstrated that CM training resulted in a number of performance advantages that were consistent with the development of some degree of automaticity in that condition. For example, CM targets were detected more reliably than VM targets. That advantage was maintained when the number of channels to be monitored was increased. However, CM performance was affected by the number of channels to be processed; this led

Eberts and Schneider (1986) to suggest that only a partial form of automatic processing had been achieved in the CM condition.

Given the central role of spatial pattern information in C^2 systems, it was considered important to more fully investigate the effects of extensive practice on the capability of subjects to develop some level of automaticity in processing such information. Therefore, experiments within the current program addressed automatic processing development with spatial pattern information representative of that found in C^2 systems. The first series of experiments dealt with the capability of subjects to automatize static spatial pattern information in both memory and memory/visual search tasks. The second series investigated the processing of dynamic spatial pattern information in visual and memory/visual search tasks.

Static Spatial Pattern Information. The initial experiment in the series (Eggemeier et al., 1990) investigated the effects of extended practice on performance under CM and VM conditions in a memory search task that required the processing of static spatial pattern information. Eberts and Schneider (1986) conducted a series of experiments with dynamic spatial patterns that required the integration of pattern elements over time. The results of these experiments had produced evidence of partial automaticity. Several types of Air Force systems require the recognition and detection of dynamic spatial pattern information, but typically, several elements of these patterns are present on the system display at any given point in time (Eggemeier et al., 1988). Thus, the demands on short-term memory to retain pattern elements in these systems can be somewhat less than the load apparently imposed in the Eberts and Schneider (1986) work. Therefore, an experiment was conducted to initially explore automatic processing development with spatial patterns similar to those required by some Air Force systems but which did not impose the requirement to integrate pattern elements over time. All pattern elements were presented in parallel as opposed to the

sequential presentation used in the Eberts and Schneider research. Three sets of such patterns were developed to represent three classes of aircraft or vehicle movement (i.e., constant movement, acceleration, deceleration) that are presented in some Air Force C² systems.

Subjects completed 4000 acquisition trials under either VM or CM conditions with these spatial patterns in a memory search paradigm. Under CM conditions, spatial patterns representing one class of movement served as targets, and those representing another class served as distractors. The use of a movement class as targets and distractors was counterbalanced across subjects. Memory set size was varied from one to four patterns. Differences in CM and VM performance over training were consistent with some level of automatic processing development in the former condition. CM was more rapid than VM performance across training; accuracy did not differ between mapping conditions. The CM group also showed an attenuation of memory set size effects on reaction time performance which characterizes the development of automatic processing. At the conclusion of training, the slope of the function relating reaction time to memory set size was almost five times greater in VM than CM. The results of this experiment support the capability of subjects to develop some level of automatic processing with static spatial pattern information intended to represent major classes of aircraft/vehicle movement found in C² systems.

The use of separate categories of target and distractor items in the initial experiment permitted subjects to distinguish between them based on a common feature (i.e., spacing of pattern elements) of the spatial patterns in each category. Therefore, it is possible that the categorization in the target and distractor sets contributed to the capability of subjects to automatize the spatial pattern sets. Because such categorization cannot be assumed in all C² systems, a second experiment

(Eggemeier et al., 1991) was conducted to investigate the development of automatic processing with static spatial patterns which did not include the categorization between target and distractor sets. To eliminate the categorization, new sets of target and distractor items were developed by randomly selecting patterns from the three categories of spatial patterns used in the initial experiment.

With the exception of the elimination of target and distractor categorization, the methodology employed was identical to that of the initial experiment. The results were consistent with those of the first experiment--CM performance was more rapid than VM performance across training. Once again, the CM group demonstrated an attenuation of the effect of memory set size on reaction time relative to the VM condition. For the VM group, the slope of the function relating reaction time to memory set size was almost twice as great as that of the CM group.

The results support the capability of subjects to develop some level of automatic processing with static spatial patterns under conditions in which target and distractor patterns are not distinguished by differences in category membership. The results of the first two experiments in this series therefore indicate that within a memory search task, subjects can develop some level of automatic processing with both categorized and non-categorized static spatial pattern information representative of that found in C^2 systems.

A third experiment (Eggemeier et al., 1992) investigated the CM and VM performance levels that could be achieved with more complex static spatial pattern information in a memory/visual search task. The memory/visual search task requires that a number of target patterns be held in memory and that subsequently presented test patterns be searched and classified as members or non-members of the set. This type of memory/visual search of spatial pattern information is a central component of important

operator functions in several Air Force C² systems such as air weapons control. The patterns were composed of six or seven elements and were intended to be more representative of the complexity found within C² systems than were the patterns used in the two previous experiments. An additional objective of the experiment was to evaluate the subjective workload associated with performance of a search task with the noted spatial pattern information. The workload results are treated in a subsequent section of this report which deals with the workload imposed by tasks under CM and VM conditions.

A total of 8000 training trials were completed under either CM or VM conditions. Memory set size--either two or four spatial patterns--was varied across blocks of ten trials. Display set size was held constant at two patterns. Subjects searched probe displays presented subsequent to the memory set and indicated the position of a target pattern through a key-press response. CM reaction time performance was superior to VM performance across training, and there was no main effect of mapping condition on performance accuracy. Within the CM group, the slope of the function relating reaction time to memory set size at the conclusion of training was less than 10 ms, while the slope of the comparable VM function was more than ten times as great. Therefore, the findings extend the results of the previous experiments to the memory/visual search conditions employed. This result is notable because memory/visual search functions constitute important components of many C² operator tasks.

The fourth experiment (Eggemeier et al., 1992) also employed complex static spatial pattern information in a memory/visual search task but included manipulations of both display set size and memory set size in order to evaluate the effects of both variables on CM and VM performance. Air Force C² systems are characterized by variations not only in the memory load imposed on the operator but in the display load as well. Therefore, the

experiment evaluated the joint effects of these two variables on CM and VM performance with static spatial pattern information. An additional objective was to evaluate the effects of whole-task versus a variant of part-task training on performance with spatial pattern information in this type of search task. The results that pertain to whole-task versus part-task training are treated in a subsequent section of this report which describes methods that can be applied to potentially facilitate the acquisition of automatic processing within consistent task components.

Subjects participated in a total of 4000 training/test trials. Memory set size was varied from two to four patterns, and display set size was either two or four patterns. Subjects indicated the location of the target pattern in the test quadrant through a key-press response. Each spatial pattern consisted of five or six elements arranged as static representations of various movement patterns associated with aircraft within Air Force C² systems.

The CM condition was associated with lower mean reaction times than was the VM condition across test sessions. As in previous experiments, attenuation of memory set size effects on reaction time was also consistent with automatic processing development within the CM condition. In this case, the slope of the function relating reaction time to memory set size was approximately four times greater in the VM condition than in the CM condition. The display set effect was also somewhat more pronounced in the VM condition relative to the CM condition, but this difference did not approach the magnitude of that obtained between the mapping conditions in memory search functions. CM performance accuracy was also superior to that of VM. In addition, neither memory set size nor display set size significantly affected the accuracy of CM performance. Both variables interacted to determine VM performance, with lower

accuracies being associated with higher memory set sizes, particularly at the display set size four condition.

The pattern of results is once again consistent with some level of automatic processing development in a CM variant of a memory/visual search task. The attenuation of the reaction time memory set size effect in the CM condition relative to the VM condition was more marked than the comparable attenuation of the display set size effect; this is also noteworthy. These data suggest that with the search display conditions and amount of training used, the level of automatic processing established has a less pronounced influence on display set size reaction time effects than on memory set size effects. This is of potential importance to eventual C^2 applications because it suggests that display set size reaction time effects would not be attenuated to the same degree as memory set size effects under equivalent levels of CM versus VM training.

Dynamic Spatial Pattern Information. The previous series of studies demonstrated results that are consistent with some level of automatic processing development with static spatial pattern information intended to represent that found in C^2 systems. Such results are important because they indicate that some degree of automatic processing of spatial pattern information can be developed for the type of memory search and memory/visual search functions required by C^2 systems.

The objective of the second series of experiments was to extend the previous work to the type of dynamic patterns that exhibit apparent motion characteristics and typify the processing requirements found in C^2 systems. The dynamic patterns processed by C^2 operators on system displays are spatial configurations that represent either radar or satellite returns associated with moving targets (e.g., aircraft, weather phenomena). As indicated above, C^2 systems require the processing of this spatial pattern information in which elements of the pattern actually move on the

system display in order to portray the speed and direction of target movement. Moreover, C^2 tasks usually require that target patterns be identified on a search display that can include both distractor patterns and random visual background stimuli (i.e., visual noise) unrelated to either target or distractor patterns.

In an initial investigation of automatic processing with the type of dynamic spatial patterns processed by C^2 operators, Lawless and Eggemeier (1990) examined performance with a weather pattern detection task. This task required subjects to search a display for complex spatial patterns that exhibited apparent motion characteristics. The display itself was complex and in the form of the state of Ohio. Visual background noise, composed of randomly spaced pattern elements, was present on the search display. Spatial pattern elements that exhibited apparent motion characteristics were displayed sequentially. However, unlike the patterns employed in the earlier work of Eberts and Schneider (1986), successive elements remained on the display for a specified period of time following their appearance. Subjects completed over 700 training trials under either CM or VM mapping conditions. Random visual background noise was progressively increased across 12 days of training. The results showed that although CM training produced a consistent advantage over VM training in the search time required to detect target weather patterns, this advantage was not statistically significant.

Several factors were potentially responsible for the failure to demonstrate reliable mapping condition differences in the Lawless and Eggemeier (1990) work. One factor involved the complexity of the weather search task. A second factor was the fact that even under low noise conditions, actual weather target patterns were difficult to discriminate from random background noise. Therefore, the Lawless and Eggemeier (1990) subjects could have been impaired in their capability to learn the distinction between target and distractor patterns because of noise on search displays throughout training. Significant

differences between CM and VM performance might have developed if training had initially taken place under no-noise search conditions that permitted more processing resources to be allocated to the target-distractor discrimination aspect of the task.

Therefore, the first experiment (Eggemeier et al., 1991) in this series investigated the effect of a no-noise training condition on the capability of subjects to perform the same weather search task used by Lawless and Eggemeier (1990). The amount of training was set at approximately the same level used in the Lawless and Eggemeier (1990) work. However, random background noise was eliminated throughout training in order to investigate performance levels that would result with training under a lower search workload condition than that employed in the previous study.

Stimuli represented weather phenomena (e.g., severe thunderstorms, tornadoes) and consisted of multi-element dot patterns with apparent motion characteristics. Each walking-dot pattern was a set of dots that grew in linear form with the addition of a new element at regular intervals which simulated radar refresh rates. After several such additions or updates, a dot pattern was formed, with each dot briefly flashing on and off in succession. Because the dots were illuminated in the order in which they appeared during successive updates, the dot elements appeared to "walk" across the screen. Both targets and distractors had apparent motion characteristics that varied along several dimensions (e.g., degree of apparent motion, heading or direction of apparent movement).

Subjects completed a total of 800 training trials under either CM or VM conditions across five training sessions. A display that showed a target pattern initiated each trial. The target display showed the physical characteristics of the pattern, but did not illustrate the randomly selected target

heading as it was to appear on a subsequent search display. The search display consisted of an outline of Ohio, the target, and two distractor walking-dot patterns. Subjects indicated the target pattern location by using a mouse interface to superimpose a cursor on the pattern.

CM performance demonstrated a response time advantage over VM performance across the final four training sessions, but this advantage was not statistically significant. Response accuracy measures also failed to produce significant differences between mapping conditions. The demonstration of a nonsignificant response time advantage was consistent with the Lawless and Eggemeier (1990) results. The similarity in the results of the two studies suggests that the presence of random background noise was not the principal factor in the failure to demonstrate mapping condition differences.

There were a number of potential reasons for the failure to demonstrate mapping condition differences in the initial experiment (Eggemeier et al., 1991) in this series. One possible difficulty was the relatively small number of training trials employed. As indicated above, automatic processing may require thousands of training trials to develop. Therefore, it was possible that more extensive training would have provided evidence of automatic processing in the CM group.

A second factor may have been the multi-stage nature and complexity of the weather pattern search task. The task used by Eggemeier et al. (1991) required subjects to search for target patterns within a relatively large and irregularly shaped area that was quite possibly associated with more complex and variable search strategies than would be expected in a typical laboratory search task. The response requirements of the weather pattern search task were also considerably more complex and potentially more variable than the discrete responses associated with most laboratory paradigms used to investigate automatic processing.

The requirement to coordinate the movement of the cursor with that of the mouse interface, as well as the continuous nature of the response, could have imposed heavier motor control demands than those of the typical paradigm.

A third possible factor was the complex nature of the dynamic weather pattern stimuli. Although the results of the previously reported data (Eggemeier et al., 1990; 1991) concerning static spatial patterns indicate that automatic processing can be established with such patterns, it is possible that the complex nature of the dynamic spatial patterns used in the first experiment either precluded the development of such processing or slowed it considerably.

Consequently, a second experiment (Eggemeier et al., 1991) was conducted to evaluate automaticity development with dynamic spatial patterns in a paradigm that reduced the visual search and response load levels present in the initial experiment. A number of changes were introduced to reduce the visual search and response requirements. First, a search display that included a single target and a single distractor pattern in two elements of a quadrant was implemented to reduce visual search requirements from the entire area bounded by the shape of Ohio. Response requirements were reduced by requiring subjects to press a key to indicate the element of the quadrant in which the target had appeared.

Some procedural differences in pattern presentation were also implemented to facilitate the subjects' capability to study and respond to the patterns. First, instead of permitting the pattern to grow into its final format with progressive additions of individual elements (as in the initial experiment), the total pattern with its apparent motion characteristics was presented. Furthermore, although different pattern orientations were presented across trials, the memory set pattern and subsequent test pattern were presented in the same orientation. The amount

of training was also increased relative to the levels employed in the initial experiment and in the Lawless and Eggemeier (1990) work.

Stimuli were once again simulated weather patterns with apparent motion characteristics that varied both in distance between elements and in element intensity to create walking-dot spatial patterns. Subjects completed 1680 acquisition trials under either CM or VM conditions in 12 training sessions. Memory set size varied from one to four patterns, and the search display size was held constant at two.

CM reaction times were significantly lower than those of the VM condition across training. There was no main effect of mapping condition on performance accuracy. At the completion of training, the memory set effect on reaction time had been markedly attenuated in the CM group relative to the VM group. During the last training session, the slope of the function relating reaction time to memory set size was four times greater in the VM versus the CM condition. The results were therefore consistent with some level of automatic processing development in the CM condition.

These results indicate that dynamic spatial patterns of the type processed by C^2 systems operators can be automatized. They also suggest that the failure to demonstrate automatic processing in the initial experiment (Eggemeier et al., 1991) and in the Lawless and Eggemeier (1990) research cannot be attributed to subjects' inability to develop automatic processing with this type of material. This result is significant because it indicates that dynamic spatial pattern information of the type found in C^2 systems is not a limiting factor in some level of automatic processing development with extended training.

Complex Alphanumeric Information

An additional important application of automatic processing to high-performance skills training concerns the complex alphanumeric information processed by Air Force C² systems operators (Eggemeier, et al., 1988). Operators of some C² systems (e.g., event detection, air weapons control) must search a display for alphanumeric characters (e.g., acronyms representing system parameters or aircraft); thus, the capability to rapidly and accurately process this type of information is an important aspect of performance in these systems.

Such complex alphanumeric information can take the form of the conjunction of letter sequences that stand for a particular system parameter and numerical values associated with the status of that parameter. In these instances, an operator can be required to search a display that contains a number of parameter designators and associated numerical values and rapidly determine whether the numerical values associated with each parameter fall within specified boundaries. This represents a rule-based search task for which the rule is defined by the conjunction of a system designator and a range of numerical values, and the search set consists of the combination of the system designator and a numerical value that represents either an exemplar or a non-exemplar of the rule.

This type of rule-based search task is conceptually similar to a semantic category search task that has demonstrated characteristics of automatic processing with extensive practice in a number of previous experiments (e.g., Fisk et al., 1990, 1991, 1992; Fisk and Schneider, 1983; Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988; Schneider and Fisk, 1984). In both tasks, a general category or rule defines the characteristics or boundaries of the search set, and in both cases, successful performance requires that single items be classified as exemplars or non-exemplars of the category or rule. However, the semantic

category search paradigm employs information categories and exemplars that have typically been well-learned prior to their application in the search task, whereas the rule-based search task requires the conjunction of system designator and numerical values not previously associated with one another.

Earlier work in the present program (Eggemeier et al., 1990) confirmed the capability of subjects to automatize letter sequences similar to those used as system component designators in C² systems. Additionally, several investigators (e.g., Fisk, Oransky, and Skedsvold, 1988; Kramer, Strayer, and Buckley, 1990) have recently demonstrated application of rule-based consistencies to automatic processing development. However, there were no previous investigations of subjects' capability to develop automatic processing in a rule-based search task involving the conjunction of alphanumeric characters required of C² system operators.

Therefore, the initial experiment (Eggemeier et al., 1992) in this series investigated the effect on performance of training under several stimulus-response mapping conditions with this type of information. A memory search paradigm was employed. Target and distractor sets consisted of complex alphanumeric rules. Each rule included a three-letter sequence (e.g., SNK, GLX) and a range of numerical values (e.g., 45-55, 25-35) associated with a particular letter sequence. These rules were the memory set items. A probe item, a single conjunction of a letter sequence and numerical value, either represented an exemplar of the rule or did not.

There were several component consistency levels within the rule-based task used in the experiment. One level concerned the association between a rule and its exemplars. To correctly respond to a test exemplar, the exemplar had to be associated with the appropriate rule. Therefore, one important aspect of skill acquisition in the task involved the association of

exemplars with the corresponding rule. A second consistency level concerned the roles played by the rules and their exemplars across training trials. Under consistent conditions, a particular rule could remain a target for an individual subject across training. Under inconsistent conditions, a particular rule could serve as either a target or distractor across training trials.

Given these different levels of task component consistency, there were several combinations of mapping conditions which characterized the tasks used in the experiment. One type of task, consistent at both the rule and rule/exemplar levels, represented a pure CM condition. The consistency at both levels not only enabled a consistent response to a rule but also permitted the association of exemplars with the appropriate rule. A second type of task was inconsistent in its use of a rule as a target or distractor across training trials but was consistent at the rule/exemplar level (i.e., the same exemplars were associated with the same rules throughout training). This represented a hybrid VM/CM condition because it was VM at the level of the role of rules as targets/distractors across trials, but CM at the level of exemplar association with a rule. Considerable learning was expected within this condition because a major component of correct responding in the rule-based search task was the association of an exemplar set with a rule. Finally, a third type of task, inconsistent at both levels, represented a pure VM condition. This condition was implemented by manipulating the conjunction of three-letter acronyms and associated numerical values on a trial-by-trial basis. This manipulation eliminated not only the consistent use of a rule as a target or distractor across training trials but also consistency of association between an exemplar set and a rule.

Subjects performed a memory search task in which the memory set varied from one to three alphanumeric rules. There was a total of 3200 acquisition trials across 16 sessions under either

the pure CM, pure VM, or hybrid VM/CM conditions described above. Reaction time during the later training stages paralleled the consistency levels within the particular conditions. The pure CM condition produced the fastest reaction times, the pure VM condition was associated with the slowest reaction times, and the hybrid VM/CM condition produced reaction times that were intermediate to the two pure mapping conditions. Although the differences between the CM and VM conditions and between the VM/CM and VM conditions were significant at all memory set sizes at the conclusion of training, the difference between the CM and VM/CM condition was significant at only the highest memory set size. At the conclusion of training, the slope of the VM function relating reaction time to memory set size was more than twice that of the CM function, while slope of the hybrid VM/CM function fell almost midway between these two extremes. Therefore, the results were consistent with some level of automatic processing development within the CM condition and also reflected the considerable learning expected to occur within the hybrid VM/CM condition.

The results are of practical importance because the data demonstrate that some level of automatic processing can be developed under memory search conditions with a task that represents a component of some C^2 operator tasks. The data also demonstrated that subjects were capable of utilizing the different consistency levels present in the complex alphanumeric search task to improve performance. This, in turn, suggests that training programs can be designed to capitalize on subcomponent consistencies, even though the task or function is not completely consistent (as in the hybrid VM/CM condition). This latter result is potentially important for eventual applications to complex C^2 operator tasks because it is unlikely that the majority of such tasks will demonstrate complete consistency. Performance improvements with training on such tasks will, therefore, at least partially rely on the capability of operators to utilize consistency at the subcomponent level.

As noted above, visual search represents an important component of operator functions within some C² systems. The first experiment addressed memory but not visual search for rule-based alphanumeric materials. Therefore, a second experiment (Eggemeier et al., 1992) was conducted with a memory/visual search task that required the subject to hold a number of alphanumeric rules in memory and search a subsequently presented set of exemplars in order to identify one that satisfied a rule in the memory set.

The memory/visual search task in the second experiment used target and distractor sets similar to those employed in the previous study. These sets consisted of complex alphanumeric rules, each of which included both a three-letter sequence and an associated range of numerical values. These rules were the memory set items. A probe item either represented an exemplar of the rule or did not. The search display consisted of four such items, and subjects were required to visually search the display set and identify the exemplar that satisfied a rule in the memory set.

Both CM and VM conditions were evaluated. Under CM search, designated rules and their associated exemplars remained targets throughout training for an individual subject, whereas exemplars of other rules served as distractors across training sessions. Within VM search, rules and their associated exemplars alternated as either targets or distractors across training trials. In the VM condition, exemplars remained consistently mapped to rules; thus, this condition actually represented a hybrid VM/CM condition of the type employed in the previous experiment. The CM and VM groups differed in the consistency present at the rule level; therefore, any mapping condition differences reflected the effect of this consistency level on performance. The effect of

training under CM and VM conditions on the workload associated with the memory/visual search task was also investigated; the results are discussed in a subsequent section of this report (Section V).

Subjects completed 1600 CM training trials and 1600 VM training trials across ten training sessions. Memory set size varied from one to four alphanumeric rules, and the display set size was held constant at four exemplars. Subjects indicated the position of the exemplar that satisfied a memory-set rule through a key-press response.

The results demonstrated a significant reaction time advantage of the CM versus VM condition across training. At the conclusion of training, memory set size exerted less of an effect on CM versus VM reaction time performance. The slope of the function relating memory set size to reaction time was more than 200 ms greater in the VM condition compared to the CM condition. CM accuracy was superior to VM performance across memory set sizes and training sessions.

Therefore, the results indicated that some level of automatic processing was achieved within the CM mapping condition, as evidenced by the superior performance under the CM versus VM condition in both the reaction time and accuracy analyses. Thus, the results extend the findings obtained with a memory search task in the initial experiment (Eggemeier et al., 1992) in this series to a task that required both visual and memory search functions. The present data indicate that the processing of complex alphanumeric information within this type of search is open to automatic processing development with training.

Summary and Discussion

The series of experiments described in this section support the capability of subjects to develop some level of automatic processing with two major classes of information that must be processed by C^2 systems operators. The last two experiments provide evidence of automatic processing in a complex alphanumeric rule-based task within memory search and memory/visual search paradigms. The memory search paradigm employed in the initial rule-based experiment incorporated several consistency levels, and following training, performance levels directly reflected the degree of consistency present in the task.

The first four experiments in the spatial pattern series provided evidence of automatic processing development under a variety of search conditions with static spatial pattern information. This information was representative of a second major class of information processed by C^2 system operators. Two of these experiments were conducted within a memory search paradigm and two within a memory/visual search paradigm. The fourth experiment, which utilized a memory/visual search paradigm, investigated the effects of both display set size and memory set size variations on performance under CM and VM conditions. The results showed that the attenuation of display set size effects under CM versus VM conditions was less pronounced than that of memory set size effects. This is of potential importance to automatic processing applications in C^2 systems because such systems can impose high levels of display load on the operator. Thus, more extensive evaluation of the attenuation of display set size effects under CM versus VM conditions is an important issue for future research.

The two experiments that investigated automatic processing development with dynamic spatial pattern information produced mixed results. The initial investigation, which involved a

complex search display and relatively complex manual response, produced a nonsignificant response time advantage in the CM condition relative to the VM condition. Therefore, the results of this experiment did not support automatic processing development within the CM condition. The second experiment reduced the visual search and response requirements of the task, introduced some modifications into the presentation of the spatial patterns, and increased the amount of training relative to the first experiment. This second experiment demonstrated reaction time advantages consistent with some level of automatic processing development within the CM condition.

Together, the results of both series of experiments indicate that some level of automatic processing can be developed with spatial pattern and complex alphanumeric information within two types of search functions performed by C² systems operators. These results are significant because they indicate that automatic processing can be developed within both memory and memory/visual search tasks that mirror the demands of some C² operator task components.

Skill Acquisition in a Complex Decision-Making Task

The research reviewed above demonstrated some level of automatic processing development within search tasks that require the processing of complex alphanumeric and spatial pattern information analogous to that found in some Air Force C² systems. An additional issue, central to the development of training programs for C² systems, concerns the capability of operators to utilize consistent components embedded within a complex task to improve performance.

To investigate consistent component training within a task representative of those found in C² systems, a complex dispatching task (Fisk et al., 1991, 1992) was developed. The

dispatching task represented a conceptual analog of the battle-resource allocation functions required of operators in real-world, battle-management tasks. It incorporated several procedural components, required learning a substantial amount of declarative knowledge, and was heavily rule-based. Participants in the task served as dispatchers and received an order during each trial for a specific amount of cargo to be delivered using one of several vehicles available for such assignments. The dispatcher's task was to select the optimal operator from a set of several choices for a given delivery based on rules governing permissible load types and levels for particular vehicles and delivery destination characteristics. Based on individual delivery orders, the dispatcher determined the range of possible operators whose licenses qualified them to deliver the cargo. To select the optimal operator with efficiency and accuracy, the dispatcher was required to associate the names of 27 operators with their corresponding license classifications. Via keystrokes, participants had access to extensive help screens that provided all declarative information and rule-based knowledge necessary to perform the task.

The dispatching task incorporated memory scanning components (e.g., maintaining in working memory the specifications of a particular job or the personnel qualified to perform it). Visual search components were also included and involved searching through help screens for relevant information. Decision components involved choosing the best operator for a particular delivery. There may be several qualified operators, but some may be overqualified and thus not cost-effective.

Although the task was quite complex, a host of consistent elements were incorporated into the overall structure. For example, the assignment of an operator to a license classification was consistently mapped. Similarly, the characteristics of deliveries that required certain license classifications were consistent (e.g., flammable liquids required

a Level 3 operator). Consequently, these consistencies allowed for performance improvements as a function of practice.

In an initial experiment (Fisk et al., 1991) that investigated skill development within the dispatching task, subjects were trained for ten hours. All subjects showed increased accuracy and increased decision speed, as well as reductions in the use of help screens and number of redundant keystrokes. Importantly, all aspects of performance improvement followed a power law of practice (Newell and Rosenbloom, 1981). Furthermore, individual differences in performance decreased as a function of task practice. Such decreases are another indicator of skill development (e.g., Ackerman, 1988; Fisk, McGee, and Giambra, 1988). This initial study demonstrated that consistency plays a critical role in learning and performance of complex tasks. Performance improvements on the complex dispatching task showed striking similarities to improvements observed in the simpler search tasks discussed above. Subsequent work with the complex dispatching task addressed the effect of part-task versus whole-task training and skill retention. These results are discussed in later sections dealing with part-task training and retention.

Factors Affecting the Acquisition of Automatic Processing

In addition to data concerning complex skill acquisition and automatic processing of materials (e.g., spatial pattern information) found in C² systems, the design of efficient training programs to support automatic processing development in components of C² tasks requires information concerning factors that can affect the acquisition of automaticity. Information concerning the influence of factors (e.g., varying degrees of task component consistency, changes in context) likely to be encountered in C² systems is critical to the design of these training programs. Likewise, data pertaining to the effects of various training variables (e.g., amount of training) and

techniques (e.g., part-task training) that might influence or facilitate automatic processing development are essential to training program design.

Therefore, several series of experiments were conducted within the present program to investigate the influence of a number of factors and techniques on the development of skilled performance within search and complex decision-making tasks analogous to components of C² operator skills. Several factors that could potentially affect automatic processing acquisition were investigated: (1) the degree of consistency present under CM conditions, (2) the effect of contextual change on skill acquisition, (3) the effect of consistent practice on memory search and visual search functions, and (4) individual differences in skill acquisition. Training variables or techniques were also examined: (1) the amount of consistent practice, (2) the effect of target prompting in the acquisition of a complex search skill, and (3) part-task versus whole-task training. Investigations pertaining to each of these areas are reviewed below. Prior to consideration of the empirical data, an overview of current theoretical positions that address the mechanisms responsible for training effects in visually-based search tasks is presented. These theories provided the conceptual framework for a number of the investigations reviewed.

Theoretical Models of Visual Search Performance

Visual search tasks analogous to functions performed by C² systems operators have been a cornerstone in traditional attention research (see Shiffrin, 1988 for a review). However, there is not a generally accepted theory of visual search performance improvement. Practice-related changes in the attentional processes involved in stimuli detection or localization have been well-documented in the visual domain, but there has been a debate in the literature for more than a decade concerning the mechanisms responsible for efficient visual search

performance (Duncan and Humphreys, 1989; Fisher, 1984; Fisher and Tanner, 1992; Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977; Treisman, 1982; Treisman and Gelade, 1980). Each of these theoretical positions is briefly described below because, prior to a review of data pertaining to improvements in visual search performance of the type found in C^2 systems, it is important to be aware of the mechanisms that have been proposed to account for such improvements. The general conclusion that can be drawn from the literature is that several learning mechanisms are involved in visual search improvement. Both efficient search strategies and attention training contribute to changes in performance that occur with practice. The following review is not exhaustive; rather, it highlights the elements of current theories that must be included in a general theory of skilled visual search.

Several theories in the literature presumably explain (or at least describe) the practice effects that occur in visual search. Shiffrin and his colleagues (Schneider and Shiffrin, 1977; Shiffrin and Czerwinski, 1988; Shiffrin and Schneider, 1977) have proposed that pure visual search benefits most from an ability to differentiate (i.e., filter) targets from distractors (see also Dumais, 1979; Rogers, 1989). According to this theory, the critical variable for performance improvement is consistency. As described above, particular items in a CM search task serve as targets or distractors but not both. Consequently, each time a particular target item appears in a display it is attended and/or responded to. After many, and sometimes thousands, of CM practice trials, an automatic response will be associated with the target item; that is, the CM target category will attract attention preferentially, relative to the other items in the display (Shiffrin, 1988). Theoretically, performance in such a CM-trained visual search task will be independent of visual load. In other words, if an automatic response is associated with a stimulus, attention-demanding search is not necessary. In a VM task, the same item might serve as a target to be attended to on

one trial but a distractor to be ignored on another. Consequently, an automatic response cannot be associated with a particular stimulus item.

Another theory of performance improvements in visual search is that proposed by Fisher (1982, 1984; Fisher and Tanner, 1992). The Fisher model is based primarily on the concept of optimal, skilled search. Individuals learn not only which features to search for but also the optimal order in which to search for them (i.e., a target feature sequence). Fisher's work has been instrumental in demonstrating that consistency of mapping targets to distractors is not the sole determinant of practice effects in visual search. Instead, featural overlap and search strategies play a critical role in the development of efficient search performance. However, consistency at a featural level is also an important variable in the Fisher model.

The Duncan and Humphreys (1989) similarity-based theory and the Treisman feature integration theory (e.g., Treisman and Gelade, 1980) do not address practice effects, per se. However, the theories do provide important information about the role of stimulus characteristics in visual search. According to the feature integration theory, visual search efficiency is a function of whether the search can be performed pre-attentively and in parallel or if it requires a conjunction of features and is a serial process. The seriality of search may also be a function of the similarity of features so that even when a conjunction of features is not required, a high degree of similarity between targets and distractors may result in serial search (Treisman and Gormican, 1988).

According to Duncan and Humphreys (1989), performance in visual search is a function of the similarities and dissimilarities of potential targets and distractors. The most efficient search occurs when there is a high degree of

dissimilarity between targets and distractors, along with a high degree of similarity among the distractor items.

These theories of performance and practice effects in visual search propose seemingly disparate mechanisms as the primary determinant of visual search performance. However, there is some evidence to support all these perspectives (Shiffrin, 1991). Visual search is a relatively complex task, and performance improvements occur on many dimensions. Important variables for performance improvement include the similarity and featural overlap of targets and distractors, the development of efficient search strategies, and an automatic response when CM targets are used.

A communality among the theories involves consistency: whenever there is consistency there will be learning. The differentiating variable among the theories is whether consistency must be at the featural level (Duncan and Humphreys, 1989; Fisher, 1984; Fisher and Tanner, 1992) or the more global, target-to-distractor level (Shiffrin and Schneider, 1977). An integrative perspective can incorporate both these consistency levels. Consistency at the featural level allows for the development of optimal search strategies. Simultaneously or subsequently, consistency of targets and distractors allows for development of an automatic response. Fisher and Fisk (1991) have suggested an alternative model of learning in search/detection tasks. According to the Fisher and Fisk view, VM search practice will, at best, allow for performance improvement due to learning an optimal search strategy. CM search practice allows for performance improvement due to learning an optimal search strategy and developing an automatic response. This alternative account of search-related skill development seems necessary to incorporate the critical elements of the above-mentioned theories, most notably, strategic search and attention training. Some data support such a view of visual

search improvement (see Fisk, Lee, and Rogers, 1991; Rogers and Fisk, 1991). However, converging evidence is needed.

Although in a different instantiation, similar ideas have been proposed by Rabbitt (e.g., Rabbitt, Cumming, and Vyas, 1979) to account for the performance improvements in tasks with a visual search component. Rabbitt states that individuals learn to use specific sets of cues to discriminate optimally between relevant and irrelevant information. Furthermore, according to Rabbitt, practice results in symbol-specific learning being superseded by other processes. Although Rabbitt does not specify what the additional processes might be, his basic ideas are consistent with the notion of general search strategies being superseded by the development of an automatic response.

The above discussion highlights that improvement in visual search is not the result of a single factor. The summary and discussion of the following experiments focus on skill development in visual-search related tasks. The experiments provide the empirical data to better understand from a training perspective the constraints that lead to the improvement of various aspects of skilled visual search.

Degree of Consistency

One of the most salient aspects of automatic/controlled processing theory, as it applies to training, is the principle that performance is limited not necessarily by the complexity of the task but rather by the number and criticality of inconsistent task components (e.g., Fisk and Schneider, 1983). In addition, a substantial amount of research has demonstrated that dramatic performance improvements occur if, and only if, consistent task components receive extensive practice. Hence, identifying consistent components is crucial to the design of efficient and effective c^2 operator training programs.

Consistency need not be all-or-none; rather, it can be defined along a continuum from 100 percent to very low levels which might even approach zero. The majority of applications-oriented research has investigated situations exhibiting the extremes on the consistency continuum. In operational settings such as those encountered in C² system tasks, perfect consistency may be unattainable. Degree of consistency, as it relates specifically to automaticity theory, was first investigated in the laboratory by Schneider and Fisk (1982b) using a relatively simple letter search task. In the Schneider and Fisk experiments, consistency was varied across conditions at levels of 100, 67, 50, 33, or 13 percent. Schneider and Fisk demonstrated a functional relationship between the amount of improvement with training and the degree of consistency. Some greatly reduced benefit relative to VM performance was found even for conditions maintaining 50-percent consistency. The Schneider and Fisk experiments notwithstanding, several questions regarding the effects of consistency on the acquisition of automatism remain. Three series of experiments (Fisk et al., 1991) within the current program were conducted to explore these issues in detail.

Degree of Consistency in High-speed Processing. An initial experiment (Fisk et al., 1991) was conducted to replicate and extend the Schneider and Fisk (1982b) results. The issue of interest was the extent to which subjects would be able to take advantage of varying levels of consistency under time-stress situations requiring moderately complex information processing. A multiple-frame word search task was used in this first experiment, thereby increasing the complexity of the information processing environment relative to that used by Schneider and Fisk (1982b). Furthermore, the presentation rate was individually adapted to test performance at the limits of the perceptual processing ability of each subject.

The experiment consisted of three phases: two training phases followed by a test phase. Both training phases included five training conditions with varied degrees of consistency (100, 67, 50, 33, and 13 percent). The different degrees of consistency were achieved by varying the number of times an item served as a distractor within a block of trials. During the first (or adaptive) training phase, the presentation speed of stimuli was a function of the accuracy level achieved by each individual subject. The goal was to train subjects to perform above threshold but near their perceptual limits. Stimulus presentation speed was adjusted after every block of 95 trials according to the following criteria: (1) if accuracy was above 75 percent for a block, the stimuli in the next block were presented 25-ms faster; (2) if accuracy was below 60 percent, the stimuli in the next block were presented 25-ms slower; (3) if accuracy was between 60 percent and 75 percent, the presentation speed did not change in the next block. The initial phase included a total of 3325 training trials. Performance improvement during this phase was assessed by stimulus presentation speeds that were associated with increased levels of performance accuracy.

Following the adaptive training phase, subjects received 2125 training trials at a fixed rate of stimulus presentation. The adaptive training in the first phase had served to adjust the stimulus presentation speed according to the abilities of each subject; the purpose of the fixed rate training phase was to provide subjects the opportunity to practice at that level. The stimulus presentation speed for this phase differed for each subject and was the fastest presentation speed attained by the subject during the last session of adaptive training.

The third phase of the experiment was conducted to determine if the appearance of items as distractors (i.e., degree of consistency) within a block of trials affected performance levels. In this final phase, each degree of consistency

condition was tested in a 100-percent consistency situation in which items were presented only as targets and never as distractors. Based upon the previous Schneider and Fisk (1982b) research, detection accuracy in search/detection tasks was predicted to be a monotonically increasing function of degree of consistency and amount of practice. The data supported this prediction.

The experiment resolved a number of important questions that were unanswered from the original Schneider and Fisk (1982b) degree of consistency study. They had examined the effects of degree of consistency on automatic process development using a relatively simple, single-letter detection task. Large amounts of practice in a VM condition produced little improvement in performance; consistent practice resulted in little benefit to performance until a substantial number of trials had occurred. Schneider and Fisk (1982b) found that a ratio of ten stimulus occurrences as a target to 20 stimulus occurrences as a distractor led to little performance improvement. The Schneider and Fisk results suggested that consistency is necessary for automatic process development. The results further demonstrated that learning is not the result of process execution but a function of consistent executions of a process. Unfortunately, from the perspective of application to more complex real-world tasks, the consistent feature in the Schneider and Fisk experiments was a letter shape. Therefore, it was not known whether degree of consistency effects would be operational in a task in which a higher-order consistency existed, despite the fact that the elemental features (e.g., specific letter shapes) were not consistently mapped.

The paradigm used in the present experiment (Fisk et al., 1991) employed a task that represented a conceptual analog of real-world, high-performance perceptual processing tasks. It required automatic detection to occur at a more global level than an individual stimulus feature. The results of the present

experiment indicated that, once subjects were performing at their limits of perceptual processing, performance improved as a multiplicative function of degree of consistency and practice. In fact, throughout the fixed training phase, there was a consistent functional relationship among practice, degree of consistency, and detection performance. The 100-percent consistency condition always yielded the highest levels of performance; the 67-percent and 50-percent consistency conditions resulted in intermediate performance levels, and the 33-percent and 13-percent consistency conditions led to poor performance. The 33- and 13-percent consistent conditions did not improve throughout the fixed frame time evaluation phase of the experiment.

The present data support the fact that consistency is necessary for performance improvement even in tasks that require complex, high-speed visual search and where consistency is defined as a combination of lower-level features (i.e., consistency is defined by high-order feature combinations). The experiment also permitted a determination of the type of contextual information that will bias performance and thus limit what can be defined as training context in search-detection-type tasks. In the current experiment, the initial context could be defined as the degree of consistency manipulation. In the pure CM testing phase, the task (and therefore the context) was changed so that the words in the 67-, 50-, and 33-percent consistent training conditions became completely consistent. This manipulation demonstrated that such a change in context did not alter the pattern of results. Performance in the previously inconsistent conditions did not immediately return to the level of the 100-percent consistent condition, nor did performance in the inconsistent conditions deteriorate.

The results of this experiment are of considerable potential importance to training consistent components of complex tasks because they extend what had been previously known about

automatic process development in situations with less-than-perfect consistency. It is anticipated that complex, real-world tasks will be characterized by task components that exhibit such levels of consistency. The present results provide additional data concerning the effects of training under these types of conditions.

Effects of Degree of Within-Category Consistency. Although the effect of high-order consistency on overall task performance has been documented (e.g., see Fisk et al., 1988), the influence of higher-level inconsistency on learning lower-level task elements and transfer performance has not been addressed by previous research. Therefore, Fisk et al. (1991) conducted an experiment to examine the interaction between consistency at the global semantic-category level versus the local individual word level. The effect of varying degrees of higher-level consistency on performance and learning was investigated. That is, the experiment examined the effect of decreases in higher-level or semantic-category consistency on performance at both higher and lower levels and investigated the issue of the level at which learning occurs in a semantic-category search task.

Subjects performed a semantic-category visual search task in which all conditions were manipulated within subjects. The experiment was divided into a training phase and a transfer phase. Subjects participated in 12 one-hour sessions in the training phase and two sessions in the transfer phase for a total of 9792 training trials and 792 transfer trials. The experimental manipulation during training was the ratio of consistent to inconsistent words within a particular semantic category. This variable defined the degree of within-category consistency. The ratios of consistent to inconsistent words used were 8:0, 6:2, 4:4, 2:6, and 0:8. These consistency conditions were manipulated between trials. Consistency condition 8:0 was completely consistent (i.e., all eight words within that particular category were consistently targets). For consistency

condition 6:2, one category, counterbalanced across subjects, was selected in which six words were consistently mapped as targets and two were variably mapped. Thus, the latter words occurred as both targets and distractors throughout training. In consistency condition 4:4, four words were consistently targets, and the other four occurred as targets and distractors. The fourth consistency condition (2:6) contained a category for which two words were consistently mapped as targets and the remaining six were variably mapped. Finally, consistency condition 0:8 was a traditional VM condition in which all the words within the remaining five categories were variably mapped.

Each training block included 16 VM (0:8) trials and eight trials with each of the other four consistency conditions (8:0, 6:2, 4:4, and 2:6). Words from the 8:0, 6:2, 4:4, and 2:6 conditions were each presented as a target once per block. In addition, each inconsistent word from the 6:2, 4:4, and 2:6 conditions served as a distractor once per block. These words occurred as distractors only on VM (0:8) trials.

The transfer phase of the experiment allowed examination of performance on trained as well as untrained exemplar words from the 8:0, 6:2, 4:4, and 2:6 trained categories. During transfer, all conditions were consistently mapped. One of the previous VM categories became a new CM category, which was included to provide a baseline performance measure. The remaining VM items served as distractors.

For both training and transfer, the dependent variables were reaction time and accuracy. The training results were quite striking in demonstrating significant performance level differences between CM and VM words. CM words were unaffected by the degree of higher-order or category consistency; however, this global consistency did affect response time to the VM words. Given the similarity of detection performance with the CM words across the conditions of within-category consistency (i.e., the

8:0, 6:2, 4:4, and 2:6 conditions), it can be argued that, in principle, consistency at any level may be used during training to facilitate task-specific performance.

Stimulus-specific performance is not the only issue to be considered. Learning can be more broadly defined as the ability to transfer to situations that are related to the trained task. The transfer phase in the preceding experiment demonstrated that global inconsistency can have deleterious effects on learning above the consistent-stimulus level. In that experiment, transfer was a function of global or within-category consistency. However, only the completely consistent category resulted in statistically significant transfer. These results are consistent with the Schneider and Fisk (1982b) degree of consistency data in which degree of consistency at the element or single letter level defined the highest-order learning. In the Schneider and Fisk experiment, only the 100-percent consistent condition resulted in a statistically significant improvement over the course of the experimental training session. However, a graded degree of consistency/performance function was obtained.

The results of the present experiment (Fisk et al., 1991) should send a message of caution to those designing training for rich, complex tasks. Real-world tasks are composed of many different levels of consistency. If lower-level consistencies are known to interfere with higher-level performance (e.g., automatically detecting certain letters when trying to read), the lower-level consistencies must be made as nonsalient as possible during training on the high-order skill; otherwise, trainees may focus on irrelevant aspects of the task or, worse yet, incorrectly learn aspects of the task.

Inconsistency and Subsequent Search Skill Acquisition.

Performance improvement with training in visual search seems to be the result of a variety of learning mechanisms (e.g., see Czerwinski, 1988; Rogers, 1991). Such improvement appears to

result from learning general search strategies and developing optimal, stimulus-specific search strategies and automatic processing (i.e., automatic attention attraction). It was suggested above that performance improvement is guided by the same factors (e.g., learning general search strategies then optimal stimulus-specific search strategies) early in practice for both CM and VM training conditions. Qualitative differences between CM and VM performance are seen late in practice and generally when the implementation of the attentive optimal search is difficult (see Czerwinski, 1988, for related views).

It seems clear that development of an optimal search strategy is critical for skilled visual search. There is some indication that training environment interacts with amount of practice with regard to developing optimal search strategies. It is known that the distribution of practice on particular target-distractor pairings affects the development of optimal search. For example, Lee, Rogers, and Fisk (1991) presented the results of a study that examined the distribution of practice across target-distractor pairings for pure CM, pure VM, and cycle conditions. The cycle conditions maintained a constant target-distractor pairing (i.e., stimulus set A was always a target set when stimulus set B was a distractor set), but the stimuli served as both targets and distractors (e.g., set A was a target set when set B was a distractor set; set B was a target set when set C was a distractor set; set C was a target set when set A was a distractor set). Hence, optimal search could more efficiently develop in the cycle conditions compared with pure VM; yet, because the stimuli were not consistently mapped as targets or distractors, an automatic process could not develop. The Lee et al. (1991) study showed that if subjects received at least ten repetitions of a given condition, optimal search strategies could develop. When repetitions were five or fewer, development of optimal search strategies seemed to be disrupted.

The Lee et al. (1991) study notwithstanding, little is known at present about how the development of optimal search strategies is affected by training environments. Therefore, Fisk et al. (1992) conducted an experiment which examined another training situation in order to learn more about factors that affect optimal search development. The experiment was conducted in two phases. The first, a degree of consistency training phase, examined the effects of training in visual search at various levels of consistency. The second phase, a consistent training phase, consisted of pure CM training. The latter phase examined the effect of the previous degree of consistency manipulation on subsequent development of skilled performance. The dependent measures in both phases were reaction time and accuracy.

The data replicated the degree of consistency effects found in the previous experiments (Fisk et al., 1991; Schneider and Fisk, 1982b) that addressed the consistency issue. Reaction time in the condition that involved manipulation of the degree of consistency was a direct function of consistency and increased as consistency decreased. All subjects exhibited good transfer from the degree of consistency phase to the consistent training phase. This was somewhat surprising, since one of the degree of consistency conditions had only 33-percent consistency and new distractors were used during the consistent training phase. This result suggested a number of potential explanations. One possibility is that the 1200 target-present trials strengthened the targets in the degree of consistency condition to a greater extent than the 2400 reversal trials weakened the attention calling strength of the target in the 33-percent consistent condition. A second possible explanation is that subjects learned optimal search strategies that were target- but not distractor-specific.

The latter explanation regarding optimal search seems somewhat unwarranted given that there was a lack of differences among the VM conditions, even though different amounts of VM

practice were received across the various degree-of-consistency groups. If optimal feature search was the primary determinant of performance improvement observed in the degree of consistency conditions, it would be expected that the VM conditions would differ and the difference between a given 100-percent consistent condition and the corresponding VM condition would be a function of the ratio of CM to VM trials.

Schneider and Detweiler (1987) have argued that target strengthening is much faster than distractor weakening. In fact, they have proposed that the difference is up to fourfold. Hence, even with 33-percent consistency, and given the number of target detections relative to reversal trials, one could expect some but not maximal target strengthening beyond a neutral level represented by new distractors. Therefore, the good transfer to the consistent training phase within the degree of consistency conditions, and the small differences between the latter conditions and the 100-percent consistent conditions during that phase, could be attributed to the target/distractor strength ratio reaching some threshold for target stimuli in both the degree of consistency condition and the 100-percent consistent condition.

These data do not argue against the development of optimal search strategies. There is substantial evidence that search strategy development can be crucial for performance improvement in visual search. However, the results do argue that the training environment may interact with other factors to reduce the development of optimal search strategies. The present data also add to the list of situations that do not support an instance-based view of automaticity (Logan, 1988). Such a theoretical perspective would have predicted poor transfer when switching between phases of the present experiment.

Contextual Change and Skill Acquisition in Visual Search

An understanding of the facilitative effects of contextual cues is critical for any training program developed to facilitate skill acquisition. A real-world example of the importance of context comes from observing skilled air-intercept controllers. Among these controllers, responses made to pilots in one context (e.g., an intercept with the goal simply to identify) are different than those made in other contexts (e.g., an intercept with the goal of defense against hostile intruders).

Fisk and Rogers (1988) investigated situation-specific contexts using a search/detection task in which context was defined as the combination of target and distractor sets. In the Fisk and Rogers experiment, a given semantic category was the target set only in the context of another particular category as the distractor set. For example, the category "Animals" might serve as the target set if "Weapons" were the distractors. However, if "Animals" were paired with "Vegetables," the "Animals" would be distractor items. Thus, the experimental context defined whether a particular set of items was attended or ignored. Fisk and Rogers (1988) found that, in the absence of traditional consistency, context can play an important role in facilitating performance. In addition, the Fisk and Rogers data supported the suggestion that context can also be important for completely consistent tasks (e.g., see Schneider and Fisk, 1984). The results from the Fisk and Rogers (1988) experiment revealed that performance in the context conditions improved more than performance in a VM condition, although not as much as in the traditional CM condition in which a particular set served as either the target set or the distractor set but not both.

Subsequent analyses of the Fisk and Rogers data suggested that the context effect seemed to occur within five exposures to the context situation (i.e., the temporary salience biasing built up very quickly and overrode previous contextual cues). Because

of the importance of this finding to understanding context effects on performance, Fisk et al. (1991) performed an additional experiment to investigate this issue in more detail. This experiment varied the number of trials per context condition in order to directly assess the temporal build-up of context effects. Context was modified either every one, five, ten, or fifty trials. Hence, the temporal nature of the acquisition of contextual benefits could be assessed. The data showed that, for this class of search tasks, temporary salience-biasing or context effects can be seen within five exposures to the context situation. Importantly, when context was shifted every trial, the benefits of context were minimized. Furthermore, the pure CM condition, which was embedded within this one-trial cycle, showed a reduction in performance improvement.

The Fisk and Rogers (1988) data and the results of this subsequent experiment suggest that contextual cues may be used to bias performance and mimic the effects of consistency. In other words, in some situations, consistencies may be context-dependent and the trainee must be aware of the critical contextual cues. This "situation awareness" may be trained by making the appropriate contextual cues most salient. After training, these cues may serve to activate particular automatized sequences of behavior.

Consistent Memory and Visual Search Practice Lead to Different Learning

From the perspective of skill acquisition theories, an understanding of search-related phenomena is important because of the close connection of those phenomena to attention issues in general and to skill acquisition issues in particular (Shiffrin, 1988). Therefore, an investigation (Fisk et al., 1992) was conducted to better understand the relationship between the type of search-detection processes used during training and what is learned during that training. The experiment investigated the

effect of being trained with one procedure (e.g., memory search) on transfer to a different procedure (e.g., visual search). Although similarities exist between memory scanning and visual search, those search processes appear to involve different processing mechanisms (e.g., Fisher, Duffy, Young, and Pollatsek, 1988; Fisk and Rogers, 1991; Flach, 1986; Hoffman, 1978, 1979). In the present experiment, subjects were trained in one of three CM search conditions: (1) pure memory search, (2) pure visual search, or (3) hybrid memory/visual search. Subsequent to the 6720 practice trials, some subjects transferred to a different search condition while the remainder served in a control condition. For example, participants trained in the pure memory search condition transferred to either pure visual search, hybrid memory/visual search, or continued to perform in the pure memory search condition. Comparable transfer conditions were also created for the other two training conditions.

The training phase of the experiment showed a striking difference between performance in conditions for which load was induced by memory set size versus display set size. The major differences between memory and visual search appear to be due to the relatively rapid speed with which memory search learning occurs. Such findings suggest that if transfer is not an issue, load should be increased via increases in memory set size or visual set size if no possibility for interaction effects with other tasks exists.

The transfer data clearly show a dissociation between task structure used during training and subsequent ability to transfer to other types of search tasks. Subjects trained in pure visual and hybrid memory/visual search were quite capable of transferring to any of the search conditions, including pure memory search. However, those trained in pure memory search demonstrated limited transfer to either pure visual or hybrid memory/visual search. Although subjects saw the same stimuli and made consistent responses to those stimuli across the training

conditions, the type of learning appeared to have been driven by the type of task performed. Such ideas have been raised previously (e.g., Fisk and Rogers, 1991; Shiffrin, 1988), but little empirical data have been available within search/detection tasks to directly assess the hypothesis. The transfer data allow the isolation of the previously proposed mechanisms responsible for automaticity in search/detection tasks. As with the degree of consistency results reported above, the present data are not well-described by an instance-based (Logan, 1988) theory of automaticity.

From a training program development perspective, the transfer results suggest that it is important to provide pure visual search training to operators who must perform consistent tasks that require pure memory search in some instances and pure visual search for the same material in other instances. Furthermore, for the noted situation, it might not be necessary to train under memory search conditions if visual search training is provided. Within the constraints imposed by the present experimental design, pure visual search training might also prove sufficient under conditions that will ultimately require combined memory/visual search.

Individual Differences in Visual Search

There is a developing literature in cognitive psychology in which researchers are taking an individual-differences approach to understanding the processes involved in skill acquisition. Of particular interest are the specific underlying abilities that are important for skill development. The logic of the approach is as follows. If a particular ability is important for successful performance of a task or task component, then individual differences in that ability should correspond to individual differences in task performance. Utilizing such an approach, it is possible to assess ability/performance

relationships across practice and make inferences about the importance of different abilities for successful performance.

To investigate performance/ability relationships in a visual search function analogous to that performed by C² system operators, a very large-scale investigation (Fisk et al., 1992) was performed which utilized 70 subjects with diverse ability levels. The experiment is important because it investigated the performance/ability relationships across multiple practice sessions on pure visual search and during reversal of target/distractor roles after substantial CM practice. The relationships between cognitive and speed abilities and performance on CM and VM visual search tasks were assessed across 6000 practice trials and 840 transfer trials. LISREL techniques were used to assess the influence of general, fluid and crystallized intelligence, working memory, perceptual speed, semantic memory access, and psychomotor speed abilities on search performance.

The results suggest that performance improvements in visual search can involve factors such as learning general and optimal search strategies and developing automatic processing. However, the type of search (CM versus VM) determines which factors are involved in performance improvements. Improvement in CM visual search represents a function of all the noted factors, while in VM visual search, it is a function of learning general and optimal search strategies. Convergent results from normative reaction time data, as well as ability/performance models for the practice and transfer sessions, supported these conclusions.

Amount of Consistent Practice

Optimization of final-level performance is the goal of most training programs designed to aid the acquisition of skilled C² operator performance. An important issue relevant to the design of training programs that will support this objective involves

the amount of practice provided on a task. Questions that are central to the development of efficient training programs involve the issues of how much practice is enough, whether additional practice is always better, and whether there is a point of diminishing returns (i.e., a point at which further practice will fail to yield substantial performance improvements). A series of experiments (Fisk et al., 1990, 1991) was conducted to address these issues.

Differences between CM and VM performance were investigated within a visual search paradigm as a function of the amount of overall training that was provided. The amount of practice was varied both between and within subjects, as well as between and within blocks of trials. In the first experiment (Fisk et al. 1990), performance levels were compared between subjects who had received either 3528, 2352, 1176, or 588 trials on both a CM and VM version of a semantic-category visual search task. At the end of training, there was greater improvement in CM versus VM performance for the first three groups but not for the group that had received 588 training trials. This result suggests that the major qualitative changes that accrue from CM practice may take nearly 1000 trials to develop; however, results reported below should also be noted. The second general pattern of training results demonstrated that, to some degree, more practice did prove beneficial. The groups receiving 3528, 2352, and 1176 training trials demonstrated faster reaction times than the group that received 588 training trials. However, none of the former groups were significantly different from one another. To assess learning and not just performance improvement, subjects were tested in a reversal task (Shiffrin and Schneider, 1977) that assessed the degree to which stimuli capture attention. The reversal task involves transfer to a situation in which originally trained targets become distractors and must be ignored during visual search. This sensitive measure of stimulus-based learning revealed significantly greater attention-attraction

strength for the 3528-trial and 2352-trial groups compared to the 1176-trial and 588-trial groups.

The initial experiment in this series did not separate the amount of time on task from stimulus-specific practice. It is conceivable that the between-subjects design that was employed may have masked some potential benefits associated with general training on the semantic-category search task. In two follow-on experiments, the amount of training was manipulated on a within-subjects basis.

In one of these experiments (Fisk et al., 1990), training was provided with all conditions intermixed within a block of trials. It was proposed that the subjects might benefit from the within-block training by forming a superordinate category containing all the CM categories. Conditions in which subjects had received 3150, 1575, or 525 CM trials were compared. As in the initial experiment, more practice yielded greater performance benefits. The 3150-trial and 1575-trial conditions were both faster than the 525-trial condition but not different from each other. However, assessment of learning using the reversal procedure to assess attention capture revealed similar learning for all three training conditions. This suggests that perhaps there was some benefit from training all conditions within blocks to facilitate the formation of a superset.

The potential benefit of within-block training on formation of supersets was explored in a third experiment (Fisk et al., 1991) in which the training in each condition was separated by blocks of trials. This experiment was designed to remove the opportunity for subjects to form a superset during training but utilized a within-subjects design that permitted time-on-task to be equated. The results were essentially the same as those from the previous experiment. These data indicated that fewer practice trials than previously suggested in the literature may be needed for performance to reach some level of proficiency.

Performance may not be automatic in the sense that it may still be resource-sensitive, may still be under the control of the subject, and so on. However, performance was certainly within the late portions of the associative or intermediate phase of skill development (Ackerman, 1988; Anderson, 1982, 1983; Fitts, 1964, 1965/1990).

The data from this series of experiments may have substantive implications for understanding the locus of CM performance improvements. When amount of training is manipulated between subjects, performance after 3000 practice trials is superior to that after 2000 practice trials, and performance after 1000 practice trials is superior to that after 500 practice trials. This supports the position that at least a partial locus of CM practice is stimulus-based. However, the experiment that manipulated practice within subjects and within blocks of trials demonstrated that performance after 3000 practice trials was not superior to that after 1500 practice trials. Performance improvement was measured in terms of asymptotic reaction time, accuracy, power function fit, etc. The final experiment replicated the latter finding using a within-subjects, between-block manipulation. Therefore, this last study ruled out the possibility of memory-set unitization as the major cause of the within-subjects training effect.

The preceding data suggest that CM practice is important for stimulus-based strengthening; however, CM practice seems to facilitate performance in another important manner. The data appear to support and extend the context activation hypothesis proposed by Schneider and Fisk (1984) as an important locus of CM training. The context activation framework assumes that consistent exposure to the training context is a critical factor leading to performance improvement. This line of reasoning suggests that neither stimulus-based target strengthening nor consistent training context is sufficient within the number of training trials presently provided to lead to automatic target

detection. Both are necessary for observed qualitative performance changes with CM practice.

These statements must be tempered somewhat because the preceding experiments did not examine performance after tens of thousands of practice trials. After such extensive practice, stimulus-based processing may supersede the training context. Schneider and Shiffrin (1977), for example, reported that subjects experienced trouble reading subsequent to CM, CRT-based letter detection training because the trained letters "popped-out" of the page. Clearly, this demonstrates that stimulus-based processing supersedes training context. However, those subjects had received thousands of practice trials.

Prompting as an Aid in Acquiring a Complex Search Skill

Extensive training is typically required before automatic performance can be realized with the type of high-performance skills required of Air Force C² operators. Schneider (1985), for example, defined high-performance skills as those requiring in excess of 100 training hours and noted that training programs for these skills often have very high failure rates. The high cost of extended training in complex skills, as represented by the simulated weather pattern detection task described earlier, emphasizes the importance of exploring techniques that might potentially reduce the required training time.

Choice reaction time represents a laboratory paradigm that can be considered analogous in some respects to target detection. If the traditional choice reaction task is altered such that stimulus alternatives are markedly increased in number and complexity, then choice reaction closely parallels the target detection found in the simulated weather pattern detection task. Wickens (1984) described factors affecting choice reactions. These parallel several variables identified in the theories of visual search performance reviewed above and can also be related

to target detection. Major influences on choice reaction/target detection (Wickens, 1984) include: (1) amount of training provided; (2) stimulus discriminability, in particular the similarity of the targets and distractors; (3) stimulus-response compatibility, the learned or naturally occurring correspondence between stimulus and response; and (4) number of stimulus alternatives and amount of information processed as revealed by the Hick-Hyman relationship (Hick, 1952; Hyman, 1953).

For target detection within background noise, the interrelated requirements of training trials, information processing, and stimulus discriminability could easily be satisfied for highly versus poorly discriminable targets. Therefore, given compatible stimulus-response channels, high rates of target detection would be expected.

Based upon the above considerations, a training model (Bower, 1991) was developed which emphasized target enhancement in target detection training. Manipulating the detectability of targets as a training function focuses the issue of how to train target detection to the problem of how to shift from artificially enhanced targets while maintaining the detectability and detection rate demonstrated under a prompted or aided condition. In effect, given easily noticed targets and compatible response methods, training becomes an issue of how to maintain the already achieved performance levels after the target prompting is removed (Bower, 1991).

To initiate some evaluation of target-based training (Bower, 1991), a series of experiments (Bower, 1991; Eggemeier et al., 1991) was conducted to evaluate the effects of different types of target prompting on performance within the previously described weather pattern detection task. Three methods of prompting the detection of target occurrences on the weather pattern search display were investigated: (1) visual target pattern intensity, in which the intensity of target pixels was manipulated;

(2) visual background noise intensity, in which the intensity of background noise pixels was manipulated; and (3) auditory prompting, in which tone pulses were presented concurrent with target pixels. Prompting could be incremented or decremented in linear steps throughout a training session. The decrementing function was incorporated because it was hypothesized that prompting, if not removed during training, would be deleterious to the learning process. Prompts not properly reduced within training could promote dependency upon the prompted features of the target, thereby precluding search and detection of non-prompted features as they normally exist.

An initial experiment (Bower, 1991; Eggemeier et al., 1991) in this series, conducted with the weather pattern detection task, confirmed the effectiveness of concurrent visual and auditory prompting in increasing target detection rates and reducing mean search time relative to a nonprompted search condition. A second experiment (Bower, 1991; Eggemeier et al., 1991), performed with the same task, investigated the effects of training under prompted target conditions on subsequent performance under nonprompted test conditions. Prompting was expected to incur a dependency upon such aiding as a function of prompted training trials. It was hypothesized that decremented prompting might alleviate the problem of dependency upon detection aids but still accrue greater overall benefits in training. A prompted group received practice using a decremented prompting procedure over three training sessions. Prompting consisted of setting the background visual noise intensity at a lower level than target intensity. Prompting was decremented by increasing noise intensity in equal steps after each practice trial. The non-prompted group received unaided practice over three comparable sessions in which background noise and target pixel intensities were maintained at equal levels.

All performance measures showed essentially the same pattern of results. Mean target detection rates were initially higher for the prompted condition compared to the nonprompted condition. These rates increased throughout training for nonprompted subjects but decreased for prompted subjects from initial highly prompted trial blocks to a value comparable to the nonprompted subjects in the later test trials. Mean search time was initially shorter for the prompted versus the nonprompted training condition but increased as prompting was reduced to become comparable to the nonprompted training condition during the final test block. As with target detection rate and search time, prompted training was initially superior in percentage of correct detections; however, this superiority declined across sessions and was eventually eliminated. Thus, the results indicated that although prompting during training was associated with superior performance under prompted test conditions, it failed to significantly affect performance during test trials in which prompting was removed.

A third experiment (Bower, 1991; Eggemeier et al., 1991) was performed to evaluate the effects on target detection performance of providing enhanced visibility of targets relative to non-targets under conditions different than those used in the previous experiments. This experiment manipulated the decrementing of prompting in sessions instead of trials. It was considered important to compare prompted and nonprompted training with a task-difficulty level that was deemed high for beginning trainees; therefore, the task-difficulty level was higher than in the initial experiment. An additional objective was to explore the use of time-based training in the weather pattern detection task. The time-based training concept was based upon the expectation that prompted subjects might benefit from the potentially greater number of training trials that could be completed in the same training time allocated to nonprompted subjects.

In the first of four 50-minute training sessions, subjects performing the weather pattern detection task under prompted conditions had target intensity set at twice the level as that utilized under nonprompted conditions. Prompted subjects also received auditory prompting during initial training trials. The nonprompted group maintained the same target intensity values over the four training sessions. The prompted subjects received decrements in target pixel intensity on each of the three sessions that followed the first; for the fourth session, target and background noise were of equal intensity.

Mean target detection rates during the early training sessions were once again higher in the prompted versus the nonprompted training conditions. However, target detection rates for the prompted training conditions fell over sessions and were statistically equivalent to those for the nonprompted training conditions during the final test session. Over the four training sessions, mean search time increased for the prompted subjects but decreased for the nonprompted subjects. There was no significant difference between the mean search times of the prompted training and nonprompted training conditions during the final test session. Once again, performance became quite similar in mean search time as prompting was removed. This suggests that prompting effects do not endure subsequent to the prompted training sessions. However, as in the previous experiment, the finding concerning search time supports a possible advantage of using prompted training. With prompting, it appears that less time is required overall to achieve performance approximately equivalent to that achieved with nonprompted training. As with target detection rate and mean search time, the advantage of prompted training was not shown in the accuracy measure when prompting was removed. Training differences under prompting versus non-prompting conditions were therefore not maintained during the test session. Prompted subjects performed a greater number of trials in the early sessions, but this number decreased when prompting levels were reduced. Nonprompted subjects

achieved fewer trials than prompted subjects in early sessions but, by the third session, were approaching the performance of prompted subjects.

The present series of experiments demonstrated that visual prompting was effective in enhancing performance within the weather pattern search task under the prompted training conditions but also showed that this advantage was not maintained when the prompting was withdrawn. It is important that the results did not demonstrate significant negative transfer to non-prompted test conditions. The data also suggest that prompting may represent a means of increasing the number of training trials per unit time. Such a capability would be of obvious practical significance to C^2 training applications. This issue and modified approaches to target prompting should be addressed in future work. Although these initial studies used relatively few trials, the finding of a training advantage in terms of search time suggests a possible role for target prompting or enhancement in operator training.

Part-Task Versus Whole-Task Training

As indicated above, automatic processing development typically requires a large number of training trials. When evaluating the feasibility of automatic processing development within components of complex C^2 skills, it is important to investigate techniques, such as the prompting procedures described above, that can potentially facilitate the acquisition of automatic processing with the types of information processed in Air Force systems. Part-task training techniques constitute an additional procedure with the potential to facilitate the acquisition of automatic processing.

A variety of part-task training methods can be applied to skill acquisition. Wightman and Lintern (1985), for example, reviewed three such methods, including segmentation,

fractionization, and simplification. Segmentation involves breaking a complex task into sequential subcomponents that are trained separately and eventually recombined into the integrated whole task. Fractionization, a second part-task training procedure, can be applied in those instances that require the concurrent performance of two or more subcomponents. This part-task training approach permits separate practice on subcomponents that would otherwise be trained concurrently. Simplification, the third part-task training technique, involves breaking a task into subcomponents that are simplified to facilitate their acquisition.

Simplification procedure variants were used in a series of experiments (Eggemeier et al., 1992; Fisk et al., 1991, 1992) that investigated part-task training effects in memory/visual search tasks with semantic-category and spatial-pattern information, and in the complex dispatching task described above.

An initial set of two experiments (Fisk et al., 1991) was conducted to investigate part-task training effects on skilled search with semantic-category information. Performance was examined as a function of the amount of to-be-learned material and the manner in which it was presented. All subjects received adaptive, frame-speed training in a multiple-frame paradigm so that performance could be examined at each subject's individual limit of perceptual processing. Stimuli were always presented above threshold. The part-task training groups received simplification, progressive part-task training on a hybrid memory/visual search task. The full task required detecting exemplars from six semantic categories within a stream of 24 display items. Little, if any, emphasis had been placed previously on the empirical examination of part-task training in this class of search tasks. It was therefore important to investigate whether part-task training would result in equivalent, inferior, or superior performance compared with full-task practice in tasks requiring associative learning (i.e.,

memory-set unitization) and automatic exemplar detection (i.e., target strengthening). The effectiveness of simplification was systematically examined using a progressive part-task training approach under conditions in which full-task participation allowed performance to be guided by both target and distractor learning in one experiment, or by just target learning in a subsequent experiment. This part-task training issue is important because many operational tasks performed by Air Force C² personnel require the learning of large numbers of categorized exemplars for fast, efficient detection. If building superset categories is not impeded by part-task training, many of the benefits of part-task training could be realized in training this present class of memory-dependent tasks.

In each experiment (Fisk et al., 1991), three conditions which represented different memory loads, but which ultimately resulted in the training of six semantic categories, were used. The conditions included: (1) part-task training of two semantic categories (PT2), which required practice of three different memory sets that each consisted of two categories, (2) part-task training of three semantic categories (PT3), which required practice of two different memory sets of three categories each, and (3) whole-task training of six semantic categories (WT6), which employed one memory set of the entire set of six categories. Under part-task training conditions, subjects trained on one memory set before advancing to the next. Subjects practiced for six days and then were tested on the whole task at various frame presentation times. After testing, subjects received another six days of practice, followed by whole-task testing.

No negative part-task training effects were observed in either experiment. All groups performed equally when the memory-set size was increased to six categories at transfer to the full-task condition. This is important because it demonstrates that memory-set unitization can occur with this type of part-task

training. The null effects pertaining to whole-task versus part-task training were not due to a lack of statistical power in the analyses performed. The null effects replicated across experiments and power analyses showed moderate to high levels of power (.75 and .73 for the initial and subsequent training experiments, respectively); this indicates a relatively low probability of failing to reject a false null hypothesis (i.e., a Type II error).

A third experiment in this series (Eggemeier et al., 1992) examined the effects of part-task versus whole-task training with static spatial-pattern information in a memory/visual search task. Results of this experiment pertaining to CM and VM conditions were described in a previous section, but the experiment also examined the issue of whole-task versus part-task training that employed a variant of the simplification procedure. Under the part-task training condition, the entire stimulus pattern set was broken down into two subsets which were alternated during training sessions. Because each subset contained only half the patterns from the entire stimulus set, this procedure permitted practice with a simpler stimulus set than the original (i.e., fewer patterns had to be maintained in memory and discriminated during any given block of training trials).

The previous two experiments (Fisk et al., 1991) in this series applied a simplification procedure variant within a semantic-category search task and demonstrated no acquisition differences between the part-task and whole-task training methods. However, the third experiment differed from the earlier studies in that the semantic-category information used in those investigations can be assumed to have been familiar to subjects before training; the spatial patterns in the third experiment were novel and had to be learned or integrated by subjects during the initial training stages. Therefore, it was considered possible that a part-task training procedure that simplified

stimulus retention and discrimination functions could facilitate performance with unfamiliar spatial-pattern materials.

Subjects completed 3200 acquisition trials under either whole-task or part-task training conditions. Following every set of 800 training trials, subjects also completed test sessions of 200 trials on the whole task in order to evaluate the effects of the two training conditions. Thus, subjects completed a total of 4000 training/test trials. CM performance was superior to VM performance and the results were consistent with some level of automatic processing development under CM training. However, there were no major effects of part-task versus whole-task training within either the CM or VM group. Memory set size had a more marked effect on performance accuracy under whole-task versus part-task training within the VM condition, but this represented the only significant effect of the training condition variable. Therefore, the results of this third experiment are consistent with the two earlier experiments and extend the previous semantic-category results to a task that involved the processing of spatial-pattern information.

The fourth experiment (Fisk et al., 1992) in this series employed the previously described complex dispatching task to investigate the potential benefits of part-task training of the memory components of the task. In addition, the study assessed the effect of prior whole-task knowledge on part-task training effects. Three variations of a part-task training component were designed to train declarative knowledge necessary for whole-task performance. Four groups of participants were trained. One group received whole-task practice on the dispatching task throughout the experiment to provide a baseline for comparison with the part-task conditions. The other three groups received training on a memory-search task consisting of declarative knowledge elements essential to the performance of the dispatching task. To investigate the effects of providing contextually-relevant instructions on training performance, two

of the part-task groups were given instructions on exactly how the material being learned would be applied in the whole task. Of these two groups, one performed the dispatching task once during training, thereby receiving a mixture of part-task and whole-task training. This alternating condition allowed examination of whether the augmentation of whole-task training with practice on a declarative, part-task component would facilitate task performance. The second part-task condition group that received initial instructions concerning the application of the declarative knowledge was termed the instruction-first group. The third part-task group did not receive contextual information about the whole task; these subjects were told only that the declarative information would be used later in a more difficult, complex task. This instruction-last condition allowed comparison of part-task training effects with and without contextually relevant instructions.

Immediately following training, participants in all conditions were transferred to one session on the whole dispatching task. The effects of the different part-task procedures were compared to those in the whole-task condition.

In the training phase of the experiment, high-performance skill development, as a function of whole-task versus part-task training, was examined. Part-task training was employed to facilitate the development of critical, declarative knowledge components requisite to performance of the whole task. The performance of individuals who received contextually relevant instructions regarding operator and destination names associated with their respective class acronyms was markedly superior to that of individuals who were instructed only that the names would be used later in a more complex task. This effect is interpretable in terms of the association of input with existing nodes in the semantic memory network. Declarative knowledge acquisition usually does not involve an entirely new set of information; rather, it involves adding more details to a well-

developed conceptual network (Glass and Holyoak, 1986). In other words, memory is partly a by-product of understanding; that is, people do not understand a description fully unless they can imagine a concrete example of what is being described (Bransford and Johnson, 1972; McFarland, 1986).

The present experimental paradigm minimizes the role of any previously existing conceptual knowledge (i.e., prior associations with the experimental stimuli). This paradigm permitted an examination of the development of a high-performance skill that places heavy demands on the working memory and memory scanning components of the human information-processing system. The provision of contextually-relevant information may have facilitated study and reaction time performance in the instruction-first and alternating conditions by allowing the assimilation of to-be-remembered input into an existing conceptual structure. In this manner, the association of operator and destination names with their respective class acronyms was facilitated.

Acquisition of dispatching task skill in the whole-task condition was characterized by dramatic improvements in total performance time early in training, with more modest improvement exhibited later. This data pattern is suggestive of power functions typically found in the skill acquisition domain (Newell and Rosenbloom, 1981). The whole-task training subjects exhibited steady accuracy improvement until reaching ceiling toward the end of training. The performance level obtained in the whole-task condition served as a reasonable baseline to which performance in the part-task conditions could be compared. Furthermore, performance in the whole-task condition was characterized by increased decision-making speed, decreased use of help screens, and a reduced number of keystrokes to complete the task.

By the end of training, performance in all part-task conditions was characterized by a high accuracy level. Clearly, all participants in these conditions effectively acquired declarative knowledge components integral to the performance of the dispatching task. Training on the dispatching task in the alternating condition, in which participants alternately practiced the memory-search and dispatching tasks, was characterized by a dramatic improvement in total time and a reasonable improvement in accuracy. Accuracy performance rivaled that seen early in whole-task training. In contrast, total time performance in the alternating condition was remarkably faster than that exhibited early in whole-task training, and as fast as that demonstrated by whole-task participants in the midtraining. Clearly, part-task training greatly facilitated development of the dispatching task skill, producing dramatic savings in total time performance.

At transfer, dispatching-task-trained participants (i.e., participants in the alternating and whole-task conditions) performed better than part-task-only-trained participants (i.e., instruction-first and instruction-last conditions). The effectiveness of whole-task training, however, was comparatively small compared to the effectiveness of providing part-task training with contextually relevant instructions. At transfer, the dispatching-task performance of participants who received contextually relevant instructions regarding the application of the to-be-learned material was markedly superior to that of participants in the instruction-last condition who were instructed only that the to-be-learned material would be used later. The advantages of whole-task-relevant instructions persisted throughout the transfer session. Data from the National Aeronautics and Space Administration (NASA) Task Load Index (TLX) subjective workload measure (Hart and Staveland, 1988) were generally consistent with the performance data.

This investigation examined the effects of part-task and whole-task procedures on skill acquisition in a relatively complex strategic planning task. Most significantly, the part-task training data clearly illustrate the necessity of providing trainees with instructions regarding the ultimate application of to-be-trained material prior to training. These data dramatically reveal the value of simplified part-task training for facilitating the development of declarative knowledge underlying the effective performance of complex decision-making tasks. Although whole-task performance was generally superior--given that maintaining a high accuracy level is ultimately the most important criterion of performance--the marked superiority of the alternating condition in total time performance is suggestive of benefits associated with that condition. Future investigations may help to elucidate a methodology by which accuracy improvement, without a concomitant reduction in speed, might be obtained.

The results of this series of investigations indicate that the variants of the simplification part-task training procedure employed in the initial three experiments had no adverse effects on the acquisition of skilled CM search performance with semantic-category and spatial-pattern information. On the other hand, the part-task training procedures employed in the initial three experiments did not significantly facilitate the acquisition of skilled search performance. However, the fourth experiment, which utilized the complex dispatching task, demonstrated a positive part-task training effect on the acquisition of declarative knowledge that was subsequently utilized within the context of the complete decision-making task.

An important issue, critical to the viability of part-task training approaches but not addressed here, concerns the potential part-task versus whole-task training effects on skilled performance retention. For example, it is possible that retention could be affected by the original training method even

though part-task training did not significantly affect acquisition in the first three experiments. Likewise, it would be important to evaluate whether the benefits of part-task training, demonstrated in the final experiment in this series, were maintained over a retention interval that did not involve performance of the complex dispatching task. These retention issues were examined in a series of additional experiments (Eggemeier et al., 1992; Fisk et al., 1991) that are described in Section IV of this report.

Summary and Discussion

The results of the series of experiments reviewed in this section provide information concerning a number of factors that can affect automatic processing under conditions relevant to the complex task environment of the type represented by C² systems. In addition, data pertaining to a number of training variables or techniques that can also influence skilled performance acquisition and automatic processing were presented.

The initial series of experiments dealt with the critical issue of the degree of task component consistency and its effects on performance within visually based search paradigms. It is likely that varying degrees of component consistency will be present within complex task elements such as those performed by C² operators. Development of additional information concerning the effects of such consistency on performance is essential both from the perspective of refining current task analytic approaches (e.g., Eggemeier et al., 1988; Fisk and Eggemeier, 1988) which support identification of task components expected to develop some level of automaticity and from the standpoint of designing training programs.

One portion of the current work extended previous data on the effects of degree of consistency to a time stress situation that required more complex information processing than had been

researched in earlier experiments. The paradigm employed represented an analog of a complex, high-performance perceptual processing task. The results demonstrated that detection accuracy was a monotonically increasing function of degree of consistency and amount of practice. An additional experiment investigated the influence of different consistency levels within a search task and examined the interaction between consistency at the global semantic-category level with that at the local individual-word level. The results demonstrated similar detection performance during training with CM words across conditions of within-category consistency and suggested that, in principle, consistency at any level can be utilized during training to facilitate task-specific performance. However, transfer data that indicated performance varied as a function of global or within-category consistency suggest that training program designers need to consider the relationship between different consistency levels. A final experimental sequence, which concerned consistency, examined the effect of a degree of consistency manipulation on subsequent skilled performance development in a search paradigm. The results demonstrated high levels of transfer from several degree-of-consistency conditions to a completely consistent training condition. Therefore, the results of this series of degree-of-consistency experiments provide data that extend previous results to high performance search task conditions. Information concerning the influence of different task consistency levels and the effects of previous training under different degrees of consistency on search task performance relevant to training program design were also provided by the data.

Additional relevant work, reviewed in this section, examined the effects of contextual cues on search performance and investigated individual differences in visual search performance. Together with previous data, the results of the contextual cues work suggest that consistencies in some situations may be context-dependent and indicate the importance of providing

situation awareness (i.e., making a trainee aware of critical contextual cues). Individual differences in visual search performance were also addressed through a very large-scale investigation that employed a large number of subjects with diverse ability levels. The relationship between cognitive and speed abilities and performance on visual search tasks was assessed under different mapping conditions. The results suggest that performance improvement in visual search can involve factors such as the acquisition of general and optimal search strategies and automatic processing. They also indicate that the type of mapping condition determines which factors contribute to performance improvement.

Both memory and visual search functions represent major performance components of C^2 systems operators. Therefore, from a training perspective, it is very important to understand what is learned during training within various search paradigms. The research reviewed above addressed this issue by investigating the effect of training with one search procedure on transfer to a different search procedure. The results show marked differences between performance under memory versus visual search conditions as a function of training and indicate that performance improved more rapidly in the former versus the latter condition. Transfer data showed that the type of learning under training conditions was driven by the type of search task performed. Pure visual search training or hybrid memory/visual search training transferred well to any search condition, but pure memory search training showed limited transfer to either pure visual search or memory/visual search paradigms. The results have important implications for the design of training programs to support the acquisition of component search skills because they suggest that if visual search and memory search of the same materials are required during performance, visual search training will be necessary.

An additional issue that represents a major factor in the design of training programs concerns the amount of practice that should be provided on consistent task elements to optimize performance. The series of three experiments described above addressed this issue under a variety of training conditions within visually based search paradigms. The results generally indicate that larger amounts of practice resulted in greater performance benefits. They also suggest the amounts of practice required to reach some level of proficiency under the search conditions tested.

The results of the previous series of experiments, as well as substantial prior research that examined automatic processing development within search paradigms, support the position that relatively large amounts of training can be required to achieve some level of automaticity within consistent tasks or task elements. The required training can be very costly; consequently, considerable utility would be associated with training approaches that might facilitate skilled performance development within consistent tasks or task components. The final two series of experiments reviewed above investigated the effects of two training approaches that had the potential to facilitate skill acquisition in search tasks relevant to C² operator functions.

The first of these two series investigated the effects of visual and auditory prompting on target detection with a complex weather pattern search task. The results indicate that although prompting was effective in facilitating target pattern detection under prompted training conditions, performance differences between prompted and nonprompted training did not persist when prompting was removed under the conditions tested. Importantly, prompted training did not lead to decrements in performance relative to nonprompted training under conditions of nonprompted performance. The results also demonstrate that prompted training has the potential to permit completion of more training trials

per unit time than nonprompted training. This suggests some potential role for target prompting within training programs designed to support the acquisition of complex pattern search skills.

The second series of training facilitation experiments examined the effects of simplification variants of a part-task training approach on skill acquisition within several visually based search tasks and within components of a complex dispatching task. The results of the search task work conducted with semantic and spatial-pattern information indicate that the versions of part-task training that were employed had no adverse effect on the acquisition of skilled search performance under CM conditions. Thus, these data support the viability of part-task training approaches under the conditions tested and indicate that part-task approaches can be applied if other training program variables (e.g., cost) suggest their use. The results of applying part-task training techniques to the dispatching task demonstrate the value of such an approach for facilitating the declarative knowledge development necessary to perform a complex decision-making task. The task was intended to represent the type of operator functions found in a battle-management environment. The dispatching task data also demonstrate the importance of providing trainees with instructions concerning the ultimate application of materials trained with part-task techniques. Thus, the data support the effective design of training programs which utilize such procedures.

III. TRANSFER OF AUTOMATIC PROCESSING

Additional important issues that pertain to the application of automatic processing to C² operator performance concern the transfer of automatic processing expected with the types of information processed by these operators. Data concerning the conditions and limits of automatic component transfer are very

important for the design of training programs intended to support automatic processing development within consistent task components. Five important issues concern: (1) transfer to untrained exemplars of trained alphanumeric rules, (2) transfer as a function of the degree of relatedness of semantic materials, (3) transfer as a function of the degree of consistency of transfer materials and the effects of such transfer on skill maintenance, (4) transfer as a function of the physical characteristics of the to-be-processed information, and (5) transfer as a function of task component recombinations. Each issue was investigated in experiments conducted during the present program; the results are reviewed in the following sections.

Transfer to Untrained Exemplars of Trained Rules

One issue relevant to the rule-based search task reported in a previous section concerns the transfer expected to untrained exemplars of the alphanumeric rules that compose the search set. Automatic processing development can require thousands of acquisition trials; therefore, significant time savings could be realized in training programs if only a limited subset of rule exemplars had to be trained. This approach could be undertaken if positive transfer of trained rules to untrained exemplars could be established.

Several previous experiments (e.g., Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988; Schneider and Fisk, 1984) have demonstrated transfer of automatic processing to untrained exemplars of trained categories within semantic category search paradigms. These results suggest that similar transfer might also be obtained within rule-based alphanumeric search tasks of the type found in C² systems. Therefore, a number of experiments were conducted to investigate extending semantic transfer results to untrained exemplars of complex alphanumeric rules. Such transfer is of theoretical interest as well because positive

transfer to untrained rule exemplars would indicate that learning during training trials had been at the rule rather than the individual exemplar level.

The first experiment (Eggemeier et al., 1992) in this series investigated transfer of pure CM, hybrid VM/CM, and pure VM training to untrained exemplars of previously trained rules with complex alphanumeric information within a memory search task. Three alphanumeric rules, which consisted of the conjunction of a three-letter sequence and a range of numerical values, were included in the memory set. Test items/exemplars consisted of a three-letter sequence and single two-digit numeral. Subjects indicated whether the exemplar satisfied a rule in the memory set by pressing a specified key. Under pure CM conditions, particular rules consistently served as targets or distractors, and exemplars were consistently mapped to rules. In the hybrid VM/CM condition, rules varied as either targets or distractors from trial to trial, but exemplars were consistently mapped to a rule. Within the pure VM condition, rules varied as either targets or distractors and exemplars were not consistently associated with a rule. Prior to the experiment, subjects had completed 3200 acquisition trials with the alphanumeric rules under one of the noted mapping conditions. They also performed an additional 400 trials during a pre-transfer session.

Two transfer conditions were investigated: (1) the Same rules with Different exemplars (S/D) than previously trained, or (2) Different rules and Different exemplars (D/D) than previously trained. The first letter designation indicates whether the alphanumeric rule used at transfer was the same or different from pre-transfer. The second designation indicates if the exemplar/nonexemplar sets were the same as those in pre-transfer. During the first transfer session, the pure CM group showed reliable positive S/D transfer relative to the D/D condition, but the remaining mapping conditions did not. This positive CM transfer is noteworthy because it indicates that some automatic

processing benefits established during training were applicable to untrained exemplars of trained rules. No transfer condition differences had been expected under the pure VM and hybrid VM/CM conditions because the inconsistency in applying the rules as targets and distractors during training should have precluded substantial rule-response learning.

A subsequent experiment (Eggemeier et al., 1992) in this series extended the results of the previous experiment to a memory/visual search task. This second experiment investigated transfer of pure CM and hybrid VM/CM training to untrained exemplars of previously trained rules with the same type of complex alphanumeric information used in the preceding experiment. In addition to evaluating performance levels that would result under the two transfer conditions, this experiment also investigated the workload associated with transfer. Workload was evaluated via the NASA TLX subjective rating scale procedure; the results are discussed in Section V. Prior to the experiment, subjects completed 1600 CM and 1600 VM trials with the rules used in this study. Two transfer sessions were performed under either S/D or D/D conditions. As in the initial experiment, only the CM group showed reliable positive S/D transfer relative to the D/D condition.

The results of this series of experiments indicate that some benefits of automatic processing established during original training with one set of exemplars can be transferred to untrained exemplars of the same rules within both memory search and memory/visual search tasks. The data suggest that the improvements in CM performance shown during acquisition sessions are at least partially attributable to learning at the rule level. This, in turn, demonstrates some automatic processing development at a level of consistency above that of the individual exemplars. From the perspective of training program development, the results of both experiments are important because they suggest that Air Force training programs could be

structured to take advantage of the rule-level transfer expected to occur with the complex alphanumeric materials used.

Transfer of Training as a Function of Semantic Relatedness

Transfer as a function of the semantic relatedness of materials has important implications for the design of training programs. As with alphanumeric rules, transfer to untrained categories related to a previously trained category indicates potential economies in training program design. Investigation of the semantic relatedness issue is also significant from a theoretical perspective because it permits investigation of two competing automatization theories via the transfer of training paradigm. In the present work, a strength-based model of automatism (Shiffrin and Schneider, 1977) was contrasted with an instance-based theory (Logan, 1988). Three experiments were conducted to examine differential predictions concerning transfer of training made by the two theoretical perspectives.

In the first experiment (Fisk et al., 1991), participants trained extensively with a single semantic category in a visual search task. Following training, the subjects performed the same task under five conditions of varied degrees of semantic relatedness (relative to the training condition). The strength view of automatism predicted a monotonically increasing relationship between degree of semantic relatedness and performance. Conversely, the instance view of automaticity predicted superior performance in the trained condition but identical performance in the other four conditions. The results showed that transfer performance increased as the degree of semantic relatedness between the original training condition and the transfer condition increased, thus supporting the strength view.

A subsequent experiment examined the persistence of learning effects as a function of semantic relatedness. Participants from the initial experiment returned after 30 days and completed one session identical to the transfer sessions of the initial experiment. The results were again consistent with the strength view of automaticity. Even after 30 days with no task exposure, transfer from the originally trained task was directly related to the semantic relatedness of the transfer task to the originally trained task.

The third study (Fisk et al., 1991) examined novice performance under the same perceptually demanding conditions as in the previous two experiments. This experiment provided a baseline performance measure and ensured that the previously obtained results were not artifactual. As predicted, there were no performance differences across the five related conditions.

The data from this series of experiments do not support at least several instantiations of the instance-based theory of automaticity. It is important to note that this instance theory failure is within the visual search task domain. Hence, the data do not argue against all applications of instance theory; rather, they indicate a limitation.

As indicated above, the findings have important implications for the development and training of many skills in terms of the transfer level to be expected in tasks in which visual search is an integral component. The data indicate that transfer is not limited to specific instances of training; thus, in this respect, they are consistent with the results of the previously described series of rule-based alphanumeric experiments. The present results indicate that transfer is determined by the relatedness of task components. Understanding the development and maintenance of skilled performance requires analysis of the tasks in terms of the consistency and, for transfer, the relatedness of the components that drive performance. This position is, of

course, not new; it was anticipated over 20 years ago by Battig (1966). However, the present data are crucial because the cognitive theory driving task analyses (e.g., strength- versus instance-based theories of automatism) will exert a major influence on the outcome of the task decomposition process. Task analysis must be conducted to find consistent components of to-be-trained tasks and also to determine those component processes that are transferrable between different but related tasks.

Task Inconsistency at Transfer and Skill Maintenance

A third transfer issue, of both theoretical and practical significance, concerns the effect of degree of task consistency on performance in a well-learned search task. Fisk et al. (1992) conducted an experiment to investigate this issue within a semantic category visual search paradigm in which highly trained performers had to adjust to different degrees of task inconsistency. In addition, the effects of varying degrees of task inconsistency on skilled search maintenance were investigated. During the initial training phase, subjects were given CM training to develop skill in visual search. Subjects then transferred (during a degree-of-consistency phase) to either 100-, 67-, 50-, or 33-percent consistent search conditions. These various conditions are referred to as degree-groups. Following practice in the degree-of-consistency phase, subjects returned during the retraining phase to 100-percent consistent search conditions. The return to consistent search allowed examination of degree-of-consistency effects on skilled performance maintenance.

The experiment investigated the importance of various possible skill development mechanisms (e.g., context, optimal search strategies, automatic processing) within a visual search task. In addition, it investigated whether a small or a large degree of inconsistency is needed to disrupt skilled search.

Finally, the work addressed whether the inability to use an automatic process or the need to inhibit an automatic process disrupts other automatic processes on nondisrupted tasks.

In the training phase, all degree-groups improved, as would generally be expected with CM training. Performance was well-described by a power function, $RT_i = 280 + bp_i^{-.2}$, where b is the initial RT and p_i is the given point in practice where RT is estimated. At the end of training, the degree-groups did not differ. Accuracy fluctuated during training, but within instructed limits. At the conclusion of training, there were no accuracy differences among the degree-groups or between the different semantic-training categories employed.

During transfer, manipulation of the degree of consistency and a change in the distractor categories disrupted performance. Reaction times increased for all conditions, but that increase was influenced by the degree of consistency manipulation. Performance in an adjusted-consistency condition, in which the degree of consistency was manipulated, was worse at lower levels of consistency. The pattern of results produced by the degree-of-consistency manipulation remained stable across the four transfer-phase sessions. In addition, those trials in a half-reversal condition, in which a previously trained CM target item served as a distractor, exhibited performance equivalent to supplemental VM performance across the four sessions of the degree-of-consistency phase. The reversal effects were strong and in line with previous studies that examined half-reversal effects within the first session of this phase. By the end of the degree-of-consistency phase, only the 67-percent degree-of-consistency group demonstrated a strong half-reversal effect. The subjects in the 50-percent and 33-percent degree-of-consistency groups showed an attenuated reversal effect within the last transfer phase session.

In the retraining phase, all subjects returned to the 100-percent consistency condition. Both the continuously-consistent condition (i.e., the within-subjects baseline condition in which consistency was 100 percent throughout all phases of the experiment) and the adjusted-consistent condition were superior to the new CM control condition, regardless of degree-group participation. Hence, it was concluded that the consistent-training benefits received during the training phase were not eliminated during the degree-of-consistency transfer phase, even for the 33-percent degree-of-consistency group. However, more detailed analyses showed that the adjusted-consistent category of the 33-percent degree-of-consistency group was more disrupted during the transfer phase than the adjusted-consistent categories of the other degree-groups.

The subjects in all degree-groups seemed to develop skilled visual search during the training phase. Their performance improved during training, with the performance-practice function fitting a general power function. Performance improvement was well-described by the "ubiquitous law" of practice (Newell and Rosenbloom, 1981), which is one indication that automatic processing had developed by the end of 6000 practice trials. In the degree-of-consistency transfer phase, performance on reversal trials indicated substantial disruption, which is another indication of automatic process development.

The pattern of performance between and within degree-groups during the transfer phase provides answers, at some level, to the questions posed in the introduction of this section. The disruption in adjusted-consistent condition target trials was a function of degree-group in that more disruption occurred as consistency decreased. Detection of targets from the continuously-consistent condition was slower in the second phase, but the slowing was unrelated to degree-group (i.e., there were no statistically significant differences among degree-groups in the continuously-consistent condition). Performance disruption

in the continuously-consistent condition was most likely due to the change from consistent distractors to new, VM distractors. Hence, because the adjusted-consistent conditions were disrupted differentially as a function of degree of consistency and the continuously-consistent condition showed minimal, uniform disruption, it can be concluded that the differential disruption of (or the differential need to inhibit) one automatic process does not necessarily differentially affect automatic processing on other tasks. This conclusion may not generalize beyond situations (such as those used in the present experiment) in which the stimuli that trigger automatic processes are segregated. However, the present finding is still important because it suggests that: (1) changes in task context will not necessarily disrupt automatic processes, and (2) inhibiting one automatic process does not necessarily lead to an inability to "let go" (Schneider and Fisk, 1983) of other automatic processes.

Some data suggest that several thousand reversal trials may be required before a well-learned automatic process is unlearned (Fisk, Lee, and Rogers, 1991; Shiffrin and Schneider, 1977). Therefore, it is not surprising that performance in the first session of the retraining phase in the adjusted-consistent condition was superior to the new CM condition, even for the 33-percent degree-group. Relative to processing new CM stimuli, the automatic process was still strong enough to benefit performance, even in the 33-percent degree-group given the change in context such that the need to inhibit action based on the output of the automatic process was removed. The data from the retraining phase suggest that disruption of a previously developed automatic process will be minimal, even when 67 percent of the well-learned stimuli occurrence requires inhibition of the automatic process and the encounter with such inconsistency is not prolonged. Given a more sensitive procedure, it may have been possible to demonstrate a more graded degree of inconsistency effect on the disruption of the automatic process. However, the disruption would be minimal.

In addition to their theoretical value, the present findings have important practical implications for the design of part-task training programs that could be developed to support automatic processing acquisition in C^2 task components. It appears that inhibiting one automatic process will not dramatically affect another if both are independent. This finding is significant because it suggests that part-task training programs can be developed to retrain one automatic process without interfering with other related but independent automatic processes.

Transfer as a Function of Physical Characteristics of To-Be-Processed Information

The effect of physical characteristic changes in automatized information is critical to the design of training programs intended to support automatic processing development in C^2 operator task subcomponents. Such changes could take various forms, including simple changes in the letter case of alphabetic information and rotation of previously trained spatial patterns. For example, C^2 systems can require the detection and processing of critical patterns in a variety of spatial rotations; therefore, it was important that the effect of such rotations be investigated.

Previous work (e.g., Eberts and Schneider, 1986; Hale and Eggemeier, 1990; Lane and Kleiss, 1985) that dealt with the effects of such changes on automatic processing has produced somewhat mixed results. Eberts and Schneider (1986), for instance, reported that the rotation of spatial pattern information under CM conditions reduced the performance level with previously trained CM patterns to the same level exhibited by VM patterns. This has important implications for the design of training programs. It suggests that programs should be designed to permit critical pattern practice under a variety of rotations in order to preserve the advantages of CM processing.

The transfer of automatic processing to patterns that have been rotated is of central importance to Air Force C² system operator training programs, because some such systems (e.g., Eggemeier et al., 1988) require that spatial patterns be processed in a variety of orientations on system displays. If automatic processing established with patterns in one orientation cannot be transferred to the same patterns under different orientations, training programs would have to be structured such that operators received practice in identifying target patterns in a variety of such orientations. Positive transfer to different orientations, on the other hand, would suggest that training programs could be limited to providing practice in target detection under a single orientation condition.

Additional investigations of the type performed by Eberts and Schneider (1986) are important to the development of training programs that permit establishment of automatic processing of spatial pattern information in C² systems. Therefore, an experiment (Eggemeier et al., 1992) was conducted to investigate the transfer that would result within CM and VM conditions in a memory/visual search task when previously trained static spatial patterns were rotated 90 degrees from their original orientation. Display set sizes of two or four patterns and memory set sizes from two to four patterns were used. Prior to the experiment, subjects performed 4800 training/test trials under either CM or VM conditions. The experiment included both a reacquisition phase that provided a baseline for assessing transfer effects and a transfer phase that required the processing of rotated patterns. During the first transfer session, pattern rotation eliminated a significant reaction time advantage of the CM versus the VM condition which had been present during the reacquisition phase. Pattern rotation increased the display set size effect on reaction time performance of both the CM and VM groups and was associated with a similar effect on CM performance accuracy. The effects of memory set size continued to be attenuated in the CM relative to the VM condition across the reacquisition and first

transfer sessions. Therefore, the pattern rotation effect on the memory search component of performance was not sufficient to eliminate this CM advantage. During the second transfer session, significant reaction time differences between CM and VM performance were re-established.

These results are consistent with those of Eberts and Schneider (1986), who also reported the elimination of CM-VM differences as a consequence of spatial pattern rotation in a visual search task. The data have implications for the design of training programs intended to establish automatic processing with spatial pattern information because they indicate that initial CM transfer performance with rotated patterns will not exhibit the speed or accuracy advantages typically associated with automatic processing. Therefore, it appears that some training with rotated patterns would be required if initial transfer is critical to operator performance. The data also provide some information regarding the probable locus of the rotation effect. A significant attenuation of the memory set size effect in the CM versus the VM condition continued to be exhibited across the reacquisition baseline and the first transfer sessions; this indicated that the pattern rotation effect was not sufficient to eliminate this automatic processing characteristic. In contrast, there was some tendency for the display set size effect to be more marked within the CM versus the VM condition at transfer. This latter trend, coupled with the continued attenuation of CM memory set size effects, suggests that pattern rotation exerted an effect on the visual search component of the CM task. Performance accuracy reflected an increase in the display set size effect within the CM condition in the first transfer session relative to the reacquisition training baseline. Thus, performance accuracy was consistent with the hypothesized locus of the rotation effect on CM performance.

The difference between CM and VM reaction time performance, which had been re-established during the second transfer session, indicates that some of the pattern rotation effects on automatic processing might be short-lived. This result further suggests that extensive training programs under different pattern rotations might not be required to re-establish some advantages of CM processing.

Physical change is also of potential importance to the type of alphanumeric information processed by C² system operators. Training devices do not always present material in exactly the same physical appearance as the actual system, and presentation of information may not always be identical across system displays. Thus, if automatic component processes are markedly affected by physical changes in the format of the information to be processed, the implications for the development of training devices to support the acquisition of such components would be significant.

Physical change in the form of letter case manipulations has been studied by a number of investigators (e.g., Hale and Eggemeier, 1990; Lane and Kleiss, 1985); the results have been somewhat mixed. Hale and Eggemeier (1990), for example, investigated the effect of physical characteristic changes in the material to be processed on transfer in a semantic-category memory search task. Three semantic transfer conditions were incorporated into the design, including transfer to: (1) the same semantic categories with the same exemplars, (2) the same semantic categories with different exemplars, and (3) different semantic categories with different exemplars. Half the subjects in each semantic transfer group experienced a letter-case switch at transfer; the remaining subjects in each group did not. The letter-case switch was used to assess the relative importance of physical versus semantic changes in the semantic search paradigm. The results indicate that semantic changes were more important than physical changes and that there was a significant physical

change effect on transfer performance. The category search task used by Hale and Eggemeier (1990) required processing items at the semantic level. Therefore, it appeared that processing letter sequences with relatively low meaningfulness in a search task that did not require semantic category processing might be more heavily dependent upon the physical characteristics of the letters in the sequences. If processing letter sequences is heavily dependent upon such physical characteristics, a case switch might have more substantial effects on this type of alphanumeric material than on the semantic materials used by Hale and Eggemeier (1990). Lane and Kleiss (1985), for example, reported significant levels of performance disruption following a letter-case switch in a CM memory/visual search task that required subjects to process individual letters.

A series of experiments (Eggemeier et al., 1990) was performed to investigate transfer with items that consisted of three-letter sequences in a memory search task. Alphanumeric materials, such as letter sequences or acronyms that stand for system parameters, represent one class of material processed by some C² systems operators (Eggemeier et al., 1988). Three transfer conditions were investigated in the present experiments: (1) a change in the physical characteristics (i.e., letter case) of the letter sequences to be processed, (2) a change in the letter sequences themselves, and (3) changes in both the physical characteristics (i.e., letter case) and the letter sequences. A control condition, in which no changes occurred at transfer, was also included.

Prior to each experiment, subjects performed 3200 acquisition trials under either CM or VM conditions. The similarity of targets and distractors was varied under CM conditions, including an instance in which the target and distractor letter sequences were highly similar and another in which they were dissimilar. Under the VM condition, targets and distractors were dissimilar. There were no significant transfer

effects of any noted manipulations under VM conditions; this suggests that minimal item-specific information had been acquired by subjects under this mapping condition during original training. This finding was not unexpected because targets and distractors continued to mix roles throughout training; thus, no consistent response to a particular letter sequence was possible. Within both CM conditions, actual letter-sequence changes led to substantially greater performance decrements than were realized under conditions that involved only a letter-case change. The magnitude of the letter-case change effect was less than one-third the magnitude of the letter-sequence-change effect in each CM condition.

The pattern of transfer exhibited in these experiments indicates that the physical change manipulation used in the current work has relatively minor effects on CM transfer performance with both similar and dissimilar target/distractor sets. It also suggests that CM performance, with this type of alphanumeric material, is somewhat robust with respect to such changes. This relatively minor case-switch effect is consistent with the results of Hale and Eggemeier (1990), who reported that the magnitude of a case-switch effect was approximately one-fifth that of a change in the semantic materials to be processed under CM category search.

The results of the current work within a memory search paradigm appear somewhat inconsistent with those of Lane and Kleiss (1985), who reported significant performance decrements and loss of load reduction effects with case-switch manipulations in a single-letter classification task. One potentially important difference between the current work and that of Lane and Kleiss is that the latter employed a combined memory and visual search paradigm rather than the pure memory search paradigm used here. This suggests the possibility that physical changes may have a more substantial impact on the visual search component of operator tasks. Previously described work (Fisk et

al., 1992) within this program demonstrated important differences between memory and visual search paradigms; the present results underscore the desirability of additional transfer work within a visual search paradigm. Such work is of potential importance to C² system applications because of the central role played by visual search in some information processing functions required of C² operators (Eggemeier et al., 1988).

Transfer as a Function of Task Component Recombinations

A final important transfer of training issue concerns possible task recombinations in which originally trained target/distractors are incorporated into a new task. The utility of part-task training methods has been extensively investigated for skill acquisition (e.g., Wightman and Lintern, 1985). Part-task training includes methods such as breaking tasks down into components through segmentation or chaining, or simplifying the task for training. Most relevant to the current discussion is the strategy of training the consistent task components. A critical consideration of this strategy is the ultimate recombination of the components into the whole task. From a pragmatic perspective, understanding high-performance-skills training must include assessments of potentially deleterious effects of incompatible automatic components on learning new skills. Rarely are trainees completely naive; therefore, it is of interest to know the effects of previous or old habits on new skill development. These issues will be of concern for the redesign of systems and will also indicate that new designs should minimize the presence of competing automatic process components. Thus, when planning part-task training of automatic components, it will be important to identify situations in which the automatic components ultimately could be incongruous with whole-task demands or other related tasks.

During the present program, a number of experiments (Eggemeier et al., 1992; Fisk et al., 1991) systemically assessed the effects of component recombination on performance. In the Fisk et al. work, subjects performed 8400 CM training trials to automatize detection in a semantic-category search task. The task components (i.e., the target and distractor sets) were then recombined in a variety of situations. The results showed positive transfer if the components were reused in a compatible manner. That is, in the target transfer condition, a specific CM-trained target set maintained its role but was paired with a new distractor set. Distractor transfer, based on the same principle, also revealed positive transfer. However, when the role of the component process was reversed (e.g., a target set became a distractor set), there was significant negative transfer. Both target and distractor reversals resulted in severe performance disruption. In conflict situations, one previously trained target set was paired with another that had been changed to a distractor set. In this case, both stimulus sets had been trained to attract attention and were thus in conflict. This situation also resulted in severe performance disruption. Finally, a distractor conflict situation (both sets had previously been trained to be ignored) showed less disruptive effects on performance. These conflict situations require the inhibition of one automatized task component and the reuse of another. These data suggest that the amount of disruption will be a function of the type of competing component. Namely, target conflict yielded greater and longer-lasting disruption than distractor conflict.

Eggemeier et al. (1992) conducted an additional experiment to investigate transfer in a memory search task involving automatic processing of static spatial pattern information. Memory set size was varied from one to four spatial patterns. Subsequent to 3200 CM training trials, subjects were transferred to one of four conditions: (1) target transfer, in which previously trained target patterns were paired with untrained

distractor patterns; (2) distractor transfer, in which previously trained distractors were paired with untrained targets; (3) complete reversal transfer, in which the roles of previously trained targets and distractors were reversed; and (4) new CM transfer, a control condition, in which both untrained targets and untrained distractors were introduced.

There was no significant effect of transfer condition on reaction time performance, although the increases in reaction time in the distractor transfer, reversal, and new CM conditions tended to be more marked relative to the training baseline than were those in the target transfer condition. Both the target transfer and distractor transfer groups demonstrated accuracy performance superior to the new CM control at the higher memory set sizes, while the reversal condition was associated with performance that did not significantly differ from the control. Thus, the pattern of the accuracy results is generally consistent with those of earlier experiments in this series which utilized a semantic-category search paradigm (Fisk et al., 1991). On a practical level, the present results suggest that some positive transfer could be expected under operational conditions that involve either target or distractor transfer with spatial pattern information within memory search tasks.

The failure to find reliable differences between the reversal and new CM control conditions was somewhat surprising, particularly because there was evidence of positive transfer in the target and distractor transfer conditions. If both target and distractor learning occurred during training, initial transfer performance within the reversal group would have been expected to be inferior to that of the new CM control. One possible explanation for the failure to find such differences lies in the nature of the spatial pattern information used in the present experiment. The initial work in this series (Fisk et al., 1991) used semantic-category information. It can be assumed that semantic-category information was well-learned by subjects

prior to participation in the experiment, but that this was not the case for the spatial pattern information in the subsequent experiment. Therefore, one requirement for correct responding in the subsequent experiment would have been the learning or integration of the spatial patterns themselves, without regard for their roles as either targets or distractors. This learning would have been required at initial transfer for both targets and distractors under the new CM condition and may have offset any disadvantage incurred under the reversal condition. This possibility could be investigated through future research that examines target and distractor transfer within a memory search paradigm with materials (e.g., letters of the alphabet, numerals) not expected to require pattern learning or integration.

Summary and Discussion

The five series of experiments discussed in this section addressed a number of issues that pertained to the transfer of automatic processing. The results demonstrate the transfer of such processing under certain conditions but also indicate important limitations on transfer under other conditions.

The first two series examined the transfer of the type of trained alphanumeric rules processed by some C² system operators to untrained exemplars and transfer to untrained semantic categories as a function of their relatedness to trained categories. Positive transfer to the untrained materials was obtained in each series. The demonstration of transfer to untrained rule exemplars is consistent with previous work (e.g., Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988; Schneider and Fisk, 1984) that demonstrated transfer of trained semantic categories to untrained exemplars and extends the previous findings to a category of information processed by C² operators. Positive transfer to untrained semantic categories that are related to trained categories also extends this previous work and indicates that some benefits of automatic processing established

with one category of semantic information can be expected for related categories as well. Semantic information is a central component of many C² operator tasks; thus, the results are of potential importance to operator training with these types of materials.

Both sets of results have theoretical as well as practical implications. At the theoretical level, both series of experiments pose some difficulties for certain versions of instance-based theories of automatic processing (e.g., Logan, 1988). Transfer to untrained materials would not be expected under typical circumstances with an instance-based theory; therefore, the results suggest that reconsidering elements of such an approach appears warranted. From a practical perspective, the results of both series of experiments indicate that, under CM conditions, some positive transfer can be expected to certain categories of untrained information. This finding has important implications for the design of training programs intended to establish automatic processing in tasks or task components requiring the processing of rule-based alphanumeric or semantic materials.

The results further indicate that the automatic processing established through training prior to transfer was at least partially at the rule or category level rather than the individual-rule or category-exemplar level. This work and other recent experiments, which have demonstrated rule-based or higher-order automatic processing (e.g., Fisk et al., 1988; Kramer et al., 1990), suggest that automatic processing can be based on consistencies above the level of the individual exemplars or stimuli processed. Complex skills, such as those required of C² operators, are likely to incorporate such consistencies; therefore, the noted research is supportive of training approaches intended to establish automatic processing in the higher-order or rule-based components of these skills.

The third transfer issue addressed in this section concerned degree of consistency effects on CM performance within a trained search paradigm. C^2 systems can be characterized by task components that exhibit varying degrees of consistency. Therefore, information concerning the effects of such levels of consistency on trained performance is essential to the effective structuring of training programs. The results of work concerning this issue indicate that although performance at transfer was affected by the degree of consistency within the transfer task, this transfer did not significantly affect performance during a subsequent retraining period in which subjects returned to completely consistent conditions with originally trained materials. As indicated above, this finding has very important implications concerning the effect of inconsistent task components on automatic processing of a separate task component.

The fourth series of experiments examined the effect of changes in the physical characteristics of spatial pattern and alphanumeric information of the type found in some C^2 systems on automatic processing. The results of work with spatial pattern information indicate that rotation of such patterns initially reduced CM performance levels to those associated with VM conditions; thus, they were consistent with the earlier work of Eberts and Schneider (1986). Since C^2 systems can require that such spatial patterns be processed in a variety of orientations, the results indicate that if initial performance levels with different orientations are critical, operators should receive some training under different orientations. An issue of practical significance not addressed by the present set of experiments is the degree of such training required to establish some specified levels of performance on patterns under various rotation conditions. In addition to the spatial pattern work, a set of experiments also examined the effect of letter-case changes on automatic processing of letter sequences intended to represent the acronyms found in C^2 systems. The results suggest that the effects of letter-case changes were relatively minor

compared with changes in the letter sequences themselves and indicate that the automatic processing of such sequences would not be completely disrupted by such a physical change. The present work, conducted within a memory search paradigm, is consistent with the results obtained by Hale and Eggemeier (1990) who researched semantic categories within a memory search task. Lane and Kleiss (1985) reported substantial disruption of automatic processing with letter-case manipulations within a memory/visual search paradigm; therefore, caution should be exercised in generalizing the current results beyond memory search functions.

The final series of experiments in this section investigated transfer of automatic processing under various task recombination conditions. The results provide evidence of both target and distractor item transfer in both visual and memory search tasks that required the processing of semantic and spatial pattern information, respectively. These results suggest that some transfer of both target and distractor pattern information could be expected under certain task recombination conditions. An unexpected result of the final experiment was the failure of the complete target and distractor reversal condition to lead to negative transfer relative to the new CM control condition. This may have reflected learning or integration requirements associated with the spatial pattern information used in this experiment.

IV. RETENTION OF AUTOMATIC PROCESSING

Skill retention is of interest in a variety of domains. For example, there are a range of situations in which personnel are trained to perform actions that are necessary only in emergency situations and, hence, infrequently used (e.g., cardio pulmonary resuscitation training). Knowledge of the retention characteristics under these circumstances will enable the most

appropriate scheduling of refresher training. Therefore, information concerning the retention functions associated with automatic processes is essential to efficiently structure training programs which will permit not only the initial acquisition of automatic processing but also its maintenance over periods of disuse.

Automatic processing retention has not been widely researched. Consequently, the automatic processing literature contains only a limited number of studies (e.g., Healy, Fendrich, and Proctor, 1990; Rabbitt et al., 1979; Shiffrin and Dumais, 1981) concerning retention. Shiffrin and Dumais (1981), for instance, discuss the results of an unpublished study by Dumais, Foyle, and Shiffrin in which automatic processing retention in visual search tasks was investigated. Retention intervals of 1.4, 2.7, and 7.2 weeks were used; CM performance proved superior to VM performance at all retention intervals. However, some forgetting occurred at 2.7 and 7.2 weeks subsequent to training. The Rabbitt et al. (1979) experiment examined performance in a CM memory/visual search task that required the detection of a memory set letter in a multielement display. Rabbitt et al. reported significant performance losses over a six-week retention interval. More recently, Healy et al. (1990) reported no significant performance loss over a one-month period in a CM visual search task that required searching for a single target letter in a multielement display. A subsequent experiment that examined retention over a six-month interval showed high retention and performance levels that approximated final acquisition levels. Thus, the results of previous experiments in visual search and memory/visual search paradigms have produced somewhat mixed results with respect to automatic processing retention.

Several series of experiments were conducted within the current program to evaluate retention functions for various materials trained under CM conditions. These experiments also

investigated a number of variables that might influence such retention. One series of experiments investigated retention functions for semantic materials and the influence of variables such as part-task training on skill retention. A second series of studies examined automatic processing retention with the type of spatial pattern and complex alphanumeric information processed by C² system operators. The influence of part-task and whole-task training, as well as the subjective workload associated with one-month retention intervals, were also examined. Finally, an experiment investigated retention in the complex decision-making task described previously in Section II.

Retention of Automatic Processing of Semantic Information

A series of experiments (Fisk et al., 1990; 1991) was conducted to investigate the retention of memory and visual search components of search-detection tasks that required the processing of semantic-category information. One set of experiments examined the retention of detection performance in memory scanning and visual search approximately one month after training. An additional set of experiments explored retention in pure visual and hybrid memory/visual search tasks at intervals of 1, 30, 90, 180, and 365 days following training. Across experiments, the results revealed no decay in CM-trained memory search and minimal decay in CM visual search. The minimal (8%) declines in visual search seemed to be related to the perceptual tuning required to perform the task. Significant declines (18%) in CM performance were largely due to performance in hybrid memory/visual search conditions. These results suggest that there was some degree of complexity in the hybrid task that was not present in either the pure memory or the pure visual search tasks. The retention data further suggest that declines in performance stabilized at approximately 30 days following training. In fact, performance at the 30-day retention interval was predictive of skill decay for retention intervals of up to one year.

A second set of two experiments (Fisk et al., 1991) was conducted to examine the effects of part-task training on the retention of skilled memory search for semantic-category information. Both experiments were conducted 30 days subsequent to the completion of the two previously described experiments (Fisk et al., 1991) that examined the effects of simplification of part-task training on the acquisition of a search skill in an adaptive, frame-speed paradigm. The results of the two acquisition experiments (Fisk et al., 1991) demonstrated no negative effects of progressive part-task training. However, even if part-task training is efficient in producing effective performance in search tasks, it is crucial to know the degree to which that performance level will be retained. For example, part-task training may be effective in training associative learning and target-strengthening, but the learning may be relatively fragile. On the other hand, learning from part-task training might be as stable as that of whole-task training. Regardless, an empirical evaluation of retention as a function of part-task versus whole-training was required.

Prior to their participation in the retention experiments, subjects received 12 days of either part-task or whole-task training during the acquisition experiments. The first retention experiment (Fisk et al., 1991) tested subjects on the exact same targets and distractors that had been trained during the acquisition experiment after a one-month retention interval. No decline in performance was found for any training group across the retention interval. The second retention experiment (Fisk et al., 1991) tested subjects with the same targets as in original training but with different distractors. In this experiment, there was a significant interaction involving training conditions and sessions which resulted from a slight improvement for both part-trained groups, while the whole-task trained group showed a decline in performance. This finding supports the notion that part-task training enabled a greater level of target

strengthening during original training than did whole-task training. To reiterate, the only instance of performance decline across the retention interval was in the whole-task training condition for the target-strengthening-only retention session during the second experiment. Hence, the lower task difficulty associated with initial part-task training was beneficial from the perspective of retaining learned targets but not when a combination of targets and distractors was to be retained.

Retention of Spatial Pattern and Alphanumeric Information

A second series of four experiments (Eggemeier et al., 1991, 1992) was conducted to investigate automatic processing retention with either spatial pattern or alphanumeric information within memory search or memory/visual search paradigms. Two experiments dealt with the retention of spatial pattern information; the remaining two investigated the retention of alphanumeric information.

The first experiment (Eggemeier et al., 1991) investigated automatic processing retention in a memory search task that required the processing of static spatial pattern information. The results of the initial series of semantic-category experiments (Fisk et al., 1990; 1991) indicate that the majority of forgetting within search paradigms occurred during the first 30 days of a one-year interval; therefore, a 30-day retention interval was employed. In addition, retention was tested at two days after completion of the last training session. At each retention interval, subjects completed two retraining sessions. This procedure assessed retention by examining the performance levels over the first set of retraining trials in each session. The procedure also assessed the capability of subjects to regain any performance losses that might have occurred during the retention interval by examining performance at the conclusion of the second retraining session. This latter issue is of practical importance because the objective of any refresher or skill

maintenance training would be to return operators to the criterion-proficiency levels achieved at the conclusion of original training.

Subjects completed 4000 acquisition trials under either CM or VM conditions during a training phase. The results of this phase demonstrate the typical advantages (e.g., speed, effect of memory load on reaction time) of CM relative to VM performance and were consistent with the development of automatic processing within the CM condition. Minimal and nonsignificant losses in reaction time performance occurred within both CM and VM conditions over both retention intervals. At the 30-day retention interval, for example, CM reaction time performance showed a three-percent decrement and VM performance a five-percent decrement. In addition to retention evaluation, comparison of the final block of retraining permitted an evaluation of the effect of relatively short retraining periods on performance. These analyses failed to show significant differences between the last training session and performance at either retention interval.

These results have important practical implications. They suggest that no retraining would be required over 30-day periods to maintain memory search performance at original levels under the conditions of training used. The results also extend the work of Fisk et al. (1990, 1991), who report no loss of performance over a 30-day interval in a pure memory search task with semantic-category information.

The results of the previously described semantic-category experiments (Fisk et al., 1990, 1991) demonstrated some performance loss over 30 days in a hybrid memory/visual search paradigm. Therefore, a second experiment (Eggemeier et al., 1992) was conducted to examine the retention of spatial pattern information within a memory/visual search task. This experiment also investigated possible retention differences that might be

associated with original part-task versus whole-task training. Prior to participation in this experiment, subjects completed 3200 acquisition trials under either part-task or whole-task training conditions. Fisk et al. (1991) evaluated the effect of a variant of a simplification part-task training procedure on the retention of semantic-category information over a one-month interval in a memory/visual search task. Under retention conditions that did not distinguish target and distractor learning, there was no effect of original training type on retention. The present experiment investigated the applicability of this finding to the retention of spatial pattern information and examined the effect of a short retraining period on performance after a one-month retention interval.

One month following original training, subjects completed two test sessions under whole-task conditions. The results demonstrated a small but significant decrement in reaction time performance under both CM and VM conditions. CM reaction time performance demonstrated a seven-percent decrement relative to the training baseline condition, while VM performance showed a ten-percent decrement. There were no retention interval effects on performance accuracy. CM performance maintained its advantage over VM performance in both reaction time and accuracy across the retention interval, and both memory set size and display set size effects tended to be greater under VM versus CM conditions. Original part-task versus whole-task training failed to exert a major influence on either the speed or accuracy of retention performance.

The effect of a short, 200-trial retraining period on performance was investigated by comparing the second session of testing at the one-month retention interval with the last session of original training. Reaction time performance had not returned to original training baselines at the conclusion of the retraining period. As in the retention analysis, higher performance levels were demonstrated in the CM versus the VM

condition. The accuracy data generally paralleled the reaction time results and demonstrated superior performance within the CM condition compared to the VM condition. There were no differences in the accuracy of CM performance between the original training baseline session and the retraining session, but VM performance showed a significant decline across these sessions. Once again, original part-task versus whole-task training failed to significantly affect reaction time performance under either mapping condition and had no effect on the accuracy of CM performance.

This experiment demonstrated a significant increase in reaction time performance in both the CM and VM conditions across the one-month retention interval employed. Coupled with the results of the previous experiment, which showed no reliable effect of a similar interval on static spatial pattern information processing within a memory search paradigm, the data suggest that retention can vary as a function of the type of search task performed. Therefore, these results are consistent with data from the previous series of semantic-category search experiments (Fisk et al., 1990, 1991). Statistically equivalent performance losses were obtained in the present experiment under both CM and VM conditions, suggesting that the reaction time increases observed over the retention interval were not specific to the automatic processing originally established within the CM condition.

The results have implications for the design of refresher training programs intended to maintain performance levels at baselines. The data indicate that some training would be required over one-month intervals to maintain reaction time performance and that a short retraining period, of the type used, was not sufficient to return reaction time performance to training baseline levels. The results do not permit specification of the amount of maintenance training required to achieve baseline levels; this should be addressed by future

research. The data demonstrate no major effect of whole-task versus part-task training on CM performance following a one-month retention interval in a task that reflected both original target and distractor learning. Thus, the data are consistent with the previously cited results of Fisk et al. (1991), who also reported no retention effect of whole-task versus part-task training under task performance conditions that were dependent upon both target and distractor item learning. However, Fisk et al. (1991) demonstrated a significant advantage to part-task training under conditions that permitted examination of target learning or strengthening.

In addition to spatial pattern and semantic information, Air Force C² systems require operators to rapidly process complex alphanumeric information, such as multiple-letter sequences (Eggemeier et al., 1988). These letter sequences or acronyms can represent various system parameters and must be rapidly and accurately identified under certain conditions to access information from system displays. A third experiment (Eggemeier et al., 1992) evaluated the retention of three-letter sequences in a memory search task. Performance was assessed after both three- and 31-day retention intervals following 3200 training trials under CM or VM conditions. Testing at each retention interval included two full retraining sessions that permitted examination of the capability to reacquire original training performance levels.

Differences between CM and VM performance at the conclusion of training were consistent with some level of automatic processing development under the CM condition. CM reaction time performance showed no significant change from training baselines and was superior to VM performance across both retention intervals. VM reaction times at the 31-day interval did not differ from those at the three-day interval. CM performance continued to exhibit a greater attenuation of the memory set size effect on reaction time than did VM performance at each retention

interval. There was no decrement in performance accuracy as a function of retention interval. In fact, accuracy at the three-day interval was superior to that during the last training session and during the 31-day retention interval.

Comparison of the final retraining session, under both retention intervals, once again permitted an evaluation of the effect of a short retraining period on CM and VM performance. Relative to the final training session, both the CM and VM groups showed some tendency to improve performance speed across both retraining sessions. CM performance was significantly faster than VM performance across these sessions. Performance accuracy was higher at the conclusion of the three-day retraining session relative to the last original training session. This finding paralleled the trend noted in the retention data.

Therefore, the data from this third experiment indicate that performance levels were essentially maintained within both mapping conditions over both retention intervals. The results extend the previously reported work of Fisk et al. (1990, 1991), who obtained no CM performance loss over a 30-day interval in a pure memory search task with semantic-category information, and the results of the initial experiment in this series, which demonstrated no retention loss with static spatial pattern information in memory search. Essentially the same results were obtained in a memory search task with alphanumeric materials in the present study.

The first three experiments in this series failed to show significant performance losses with spatial pattern and alphanumeric information within memory search paradigms but demonstrated losses within a memory/visual search paradigm with spatial pattern information. Therefore, a fourth experiment (Eggemeier et al., 1992) was performed to investigate automatic processing retention in a memory/visual search task that required the processing of rule-based complex alphanumeric information.

In addition to the performance assessment, a retention interval effect on the subjective workload associated with task performance was investigated. The workload results are detailed in the next section of this report.

Retention was tested after a 26-day interval, which approximated the one-month intervals that were used in the previous experiments of this series. Subjects performed a memory/visual search task that required the processing of the same alphanumeric rule information described in Section II of this report. These rules required the conjunction of a three-letter sequence with a specified range of numerical values and were intended to represent a type of complex alphanumeric information processed by C² system operators. Subjects completed 3200 original training trials and 640 transfer trials in experiments conducted prior to the retention experiment. An acquisition session and a retention session, which was conducted 26 days subsequent to the acquisition session, were included in this experiment. The acquisition session, consisting of 320 additional training trials, served as a training baseline for the assessment of retention effects.

Reaction times in the retention session showed a significant decrement under both mapping conditions relative to the training baseline. CM reaction time performance showed a ten-percent decrement relative to the training baseline, while VM performance demonstrated a six-percent decrement. The difference in decrements between mapping conditions was not statistically significant, and the overall CM performance levels were superior to those of VM. At the conclusion of training, the memory set size effect tended to be attenuated in the CM versus the VM condition; this attenuation remained quite stable over the retention interval. CM performance accuracy was superior to that of VM across the retention interval, and the memory set size effect was attenuated in the CM versus the VM condition. There was no significant accuracy loss over the retention interval.

Thus, this series of four experiments demonstrated no significant performance loss in either CM or VM conditions over one-month intervals with memory search tasks. However, it did show significant losses under both mapping conditions in memory/visual search. The previously reported series of experiments with semantic-category information (Fisk et al., 1990, 1991) showed greater retention decrements in memory/visual search task relative to pure visual or pure memory search tasks. The pattern of results across the two series of experiments suggests that the type of task performed may have an impact on retention interval effects on performance. Therefore, the results indicate that this variable should be considered in the development of training programs for Air Force C² operators.

Retention of Complex Decision-Making Skills

In addition to the various visual and memory search tasks that represent components of C² operator performance, it is necessary to specify retention functions for the complex decision-making task described in Section II of this report. A dispatching task was developed (Fisk et al., 1991, 1992) to represent a conceptual analog of the battle-resource allocation required in actual battle-management tasks. As indicated previously, the task required choosing the optimum driver for a specific delivery on the basis of rules and license classes which determine the qualified drivers. Thus, the dispatching task incorporates substantial rule and procedural components and requires that a large amount of declarative knowledge be acquired. There are also memory scanning and visual search components as well as a number of consistent elements. Memory scanning components are related to functions such as maintaining job specifications or personnel information in working memory, and visual search requirements include searching through various help screens for relevant information.

A retention experiment (Fisk et al., 1992) that utilized this complex dispatching task was conducted 60 days subsequent to a training experiment described in Section II. Four groups were incorporated into the training experiment; one received whole-task practice on the dispatching task throughout the experiment and the other three groups received part-task training on a memory-search task consisting of declarative knowledge elements essential to dispatching task performance. Two of the part-task groups were instructed on exactly how the material being learned would be applied in the whole task. Of these two groups, one actually performed the dispatching task during training, thereby receiving a mixture of part-task and whole-task training. This alternating condition permitted examination of whether augmentation of whole-task training with practice on a declarative, part-task component would facilitate performance. The second, or instruction-first part-task training group, did not receive whole-task practice but was given initial instructions concerning application of the learned material to the whole task. The third part-task group did not receive contextual information about the whole task; these subjects were told only that the declarative information would be used later in a more difficult, complex task. This instruction-last condition allowed comparison of part-task training effects with and without contextually-relevant instructions. Immediately following training, participants in all training conditions were transferred to the whole dispatching task.

Comparison of this baseline transfer performance with 60-day retention performance revealed considerable variability across the different training conditions. Whole-task participants were able to maintain a consistently high degree of accuracy across the retention interval. However, the cost of this maintenance was a reduction in total time performance--which declined noticeably. In the alternating condition, there were modest declines in both accuracy and total time performance. There was no noticeable decline in speed for the part-task memory-search-

only conditions (i.e., instruction-first and -last groups). However, the pattern was different for the retention of accuracy. The absence of contextually-relevant instructions resulted in a noticeable accuracy reduction in the instruction-last condition, while in the instruction-first condition accuracy declined only slightly.

Among the various training conditions at retention, the relative rankings of the conditions were generally maintained across the retention interval. First, performance in the whole-task condition was strikingly superior in terms of accuracy. Conversely, performance in the alternating condition was markedly superior in terms of speed. Again, the lack of contextually relevant instruction on the dispatching task resulted in the poorest accuracy performance for the instruction-last condition. Finally, all conditions improved across blocks in the retention phase, both in accuracy and total time.

This investigation examined the effects of part-task and whole-task procedures on skill retention in a relatively complex strategic-planning task. The part-task training data clearly show the necessity of providing trainees with prior instructions regarding the ultimate application of the material to be learned. Coupled with the results of the previously described acquisition experiment (Fisk et al., 1992), the data demonstrate the value of simplified part-task training for facilitating the development and retention of declarative knowledge underlying the effective performance of complex decision-making tasks. Original whole-task training performance was generally superior, as indexed by the criterion of maintaining a high accuracy level. However, the superiority of the alternating condition in total time performance reveals benefits of this approach as well.

Summary and Discussion

The series of experiments reported above, all of which examined automatic processing retention within several major categories of search tasks, generally demonstrated minimal performance losses over one-month intervals within pure memory and pure visual search paradigms. This was true of the semantic information examined within both visual search and memory search tasks, and for the spatial pattern information and alphanumeric information investigated within the latter type of paradigm. When significant retention losses did occur, they were associated with more complex hybrid memory/visual search paradigms. Such retention decrements were demonstrated in experiments dealing with memory/visual search which employed not only semantic-category information but also spatial pattern and complex alphanumeric information. The pattern of results within the present studies is consistent with earlier work that demonstrated retention decrements within memory/visual search (Rabbitt et al., 1979) but not with pure visual search (Healy et al., 1990). Therefore, it appears that the task type may affect retention functions within the search paradigms investigated in this program. In several experiments, VM conditions showed retention losses that were statistically equivalent to CM conditions; this suggests that the locus of performance decrements within memory/visual search tasks was not specific to the automatic processing components of CM tasks. Fisk et al. (1991) hypothesized that the noted retention losses might reflect decrements in the controlled processing associated with the linkage of the visual and memory search components of such tasks.

The influence of original part-task versus whole-task training on retention was investigated in a number of experiments. The results from memory/visual search tasks, which were dependent upon both original target and distractor learning, demonstrated no influence of this variable on retention. This was true of both semantic category and spatial pattern

information. However, a study within a semantic-category, memory/visual search task that examined retention for targets alone indicated that targets trained under part-task conditions were retained better than targets trained under whole-task conditions. This latter finding suggests that part-task training can facilitate retention of certain task components and represents an important area for additional research. Part-task training of selected components of a complex dispatching task proved beneficial under conditions in which subjects were informed of the relationship between the trained component and the overall task at the beginning of training. The 60-day retention data generally paralleled differences between the part-task training conditions that were present at the conclusion of original training.

The present results have important implications for the design of training programs intended to support automatic processing development within C² operator task components. The results suggest that over one-month intervals of disuse, automatic processes will be somewhat resistant to performance decrements. Work within the present program, which examined retention after one year, suggests that decrements after one-month are highly predictive of decrements that will be observed over a year. Consequently, it appears that automatic processes would prove resistant to substantial forgetting over the latter period of time. The more pronounced retention losses observed under memory/visual search conditions versus memory or visual search alone, as well as the equivalence of loss under CM and VM conditions in such circumstances, suggest that the losses may be in controlled processing elements of complex tasks, and not in the automatic components themselves. This, in turn, suggests that refresher or maintenance training might be required over one-month periods of disuse to maintain controlled processing which is essential to performance within most complex skills.

V. WORKLOAD UNDER CONSISTENTLY MAPPED AND VARIABLY MAPPED CONDITIONS

A principal automatic processing characteristic is a reduction in the workload or expenditure of information processing resources associated with task performance. Such reductions are of great potential importance to C^2 system operators because of the high levels of task demand that can be imposed by these systems. Thus, assessment of the workload associated with automatized tasks or task components represents an important consideration in evaluating automatic processing effects on functions representative of those performed by C^2 systems operators.

A large number of assessment techniques can be applied to assess operator workload (e.g., Eggemeier and Wilson, 1991; Hart and Wickens, 1990; Wilson and Eggemeier, 1991). Most empirical assessment techniques can be classified as belonging to one of three major categories of measurement procedures: (1) subjective techniques, (2) performance-based procedures, and (3) physiological techniques. Subjective techniques require the operator to judge the workload imposed by performance of a task or function, and report that judgement through a procedure such as a rating scale. Performance-based techniques provide an index of workload through measurement of operator performance levels. There are two major sub-categories of performance-based techniques: (a) primary task measures, which assess the operator's ability to perform the task or function of interest; and (b) secondary task methodology, which derives a workload measure from the operator's ability to perform the primary task and a concurrent or secondary task. Physiological measures, the third major category of assessment procedures, provide a workload index through some measure of the operator's physiological response to task demand. Measures of cardiac and central nervous system functions are examples of procedures that have been

employed to assess workload (e.g., Hart and Wickens, 1990; Wilson and Eggemeier, 1991).

Several experiments conducted as part of the current effort investigated the workload associated with CM task performance through application of either subjective procedures or secondary task methodology. One set of experiments (Eggemeier et al., 1992) investigated the subjective workload associated with memory/visual search tasks with complex alphanumeric and spatial pattern materials intended to represent major classes of information processed by C² system operators. These experiments were described earlier in this report. The results of the workload analyses will be described in this section. A final experiment in this group applied secondary task methodology to assess the workload associated with a memory/visual search task that required the processing of spatial pattern information. A discussion of this experiment concludes this section.

Subjective Assessment of the Workload Associated with Consistently Mapped and Variably Mapped Task Performance

Subjective measurement techniques are one of the most frequently applied methods of assessing operator workload within complex systems (e.g., Eggemeier and Wilson, 1991; Hart and Wickens, 1990). Research conducted over the past ten years has produced a number of subjective assessment techniques with demonstrated sensitivity to variations in operator workload. One of the more extensively researched subjective measurement procedures is the NASA TLX (Hart and Staveland, 1988) technique. The TLX is a multidimensional approach to operator workload assessment that requires subjects to rate on each of six subscales which represent dimensions (e.g., mental demand, effort) assumed to contribute to operator workload (Hart and Staveland, 1988). The TLX technique has been successfully applied to discriminate workload levels in a number of multiple-

task or systems environments (e.g., Eggemeier and Wilson, 1991; Hart and Wickens, 1990). This technique was the rating scale procedure used to assess the subjective workload associated with CM and VM task performance in the present series of studies.

Relatively few experiments (e.g., Vidulich and Pandit, 1986, 1987; Vidulich and Wickens, 1986) have employed subjective procedures to assess the workload associated with CM and VM task conditions. Vidulich and Pandit (1986), for example, used the NASA-Bipolar technique (Hart, Battiste, and Lester, 1984) to assess the subjective workload associated with a semantic category memory search task under CM and VM conditions. The bipolar technique, a precursor to the TLX procedure, required ratings on nine bipolar scales that represented dimensions assumed to contribute to mental workload. Mapping condition was a between-subjects variable in the Vidulich and Pandit (1986) work, and memory set size was either one or four semantic categories. Vidulich and Pandit reported no significant main effect of mapping condition on workload ratings. However, memory set size had a less marked effect on CM than VM workload ratings. In another application of subjective assessment techniques to CM and VM task conditions, Vidulich and Wickens (1986) evaluated mapping condition effects on subjective workload ratings under single- and dual-task conditions. A memory search task which employed letters was practiced under CM and VM conditions in a within-subjects design. The data reported by Vidulich and Wickens (1986) showed that lower workload ratings were associated with the CM versus VM condition during single-task performance, but also that the magnitude of these differences was reduced under a dual-task condition that involved concurrent performance of a compensatory tracking task. Finally, Vidulich and Pandit (1987) employed the NASA TLX procedure to assess subjective workload in a memory/visual search task which required subjects to process alphanumeric characters under CM and VM conditions. Mapping condition was a within-subjects variable. TLX ratings associated with CM performance were reliably lower than those

associated with VM performance. Thus, work conducted to date indicates that subjective measures can be successfully employed to discriminate memory set size effects associated with CM and VM conditions and, in some instances, also show that lower overall workload levels are associated with CM as opposed to VM conditions.

Some C² operators must process complex alphanumeric information in the form of the rule-based memory/visual search task discussed above. These rules consist of the conjunction of an acronym or letter sequence that signifies a system parameter and a range of numerical values associated with that parameter. None of the previously cited experiments (Vidulich and Pandit, 1986, 1987; Vidulich and Wickens, 1986) assessed the workload associated with the performance of such a complex alphanumeric task. The results of an experiment (Eggemeier et al., 1992) conducted within this program, which demonstrated the capability of subjects to develop some level of automatic processing with such materials in a memory/visual search task, was described in Section II. Subjects completed 1600 CM and 1600 VM acquisition trials. Mapping condition represented a within-subjects variable. At the conclusion of training, CM performance was more rapid than VM performance and also showed an attenuation of the memory set size effect on reaction time. In addition to assessing the performance levels associated with CM and VM versions of the rule-based memory search task, the workload associated with these variants was measured via the NASA TLX rating scale technique. Overall workload ratings derived from the TLX procedure showed that workload associated with the CM condition was consistently lower than that associated with the VM condition. Workload ratings decreased as a function of training within both mapping conditions; however, these decreases were somewhat more marked in the VM versus the CM condition. This effect can be attributed to the substantially lower workload of the CM versus the VM condition during the initial session. Thus, CM workload may have demonstrated a more restricted range of

reduction than was true in the VM condition. The analyses of the TLX ratings indicated that the workload levels associated with CM processing of complex alphanumeric information were lower than those associated with VM processing under comparable conditions.

Two subsequent experiments (Eggemeier et al., 1992), performed with the same memory/visual search task, evaluated the subjective workload associated with transfer and retention of complex alphanumeric materials under CM and VM conditions. The performance-based results of these studies have been reviewed in earlier sections of this report. However, the NASA-TLX technique was also applied to investigate the workload associated with CM and VM performance under the transfer and retention conditions.

In the transfer experiment (Eggemeier et al., 1992), subjects who received 1600 CM and 1600 VM acquisition trials in the experiment described above were transferred to either an S/D or a D/D condition. The S/D condition involved the same rules as original training but with different exemplars, while the D/D condition involved different rules and different exemplars. There were two transfer sessions of 320 trials each. Subjects completed subjective workload ratings at the conclusion of each session. CM workload was rated as lower than VM workload at transfer. It had been predicted that the CM-S/D group would result in lower levels of subjective workload than either the CM-D/D group or the VM transfer groups. Although workload levels associated with the CM-S/D condition were consistently the lowest among all the transfer conditions, this trend was not statistically significant. Given the significant differences between CM and VM conditions maintained at transfer, it is possible that the most pronounced workload advantages associated with CM-S/D condition relative to the CM-D/D condition were relatively short-lived and that workload ratings gathered at the completion of a session of 320 trials might not reflect any initial advantage.

The retention experiment (Eggemeier et al., 1992) evaluated the workload associated with performance of the memory/visual search task with rule-based alphanumeric materials over a 26-day retention interval. The results showed a significant increase in the rated workload associated with task performance in both mapping conditions over the retention interval. The CM condition showed a 41-percent increase in workload relative to a training baseline, while the VM condition showed a 54-percent increase. Despite the increases in rated workload associated with the retention interval, the significantly lower levels of CM versus VM workload established during original training remained. Thus, the rated workload results generally paralleled the previously reported performance data.

An important result that emerged across the last two experiments in this series concerns the stability of workload differences between mapping conditions. In each experiment, the lower levels of rated workload associated with CM versus VM conditions developed during original training with complex alphanumeric materials remained under the transfer and retention conditions examined.

In addition to work with alphanumeric materials, a previously described sequence of search experiments (Eggemeier et al., 1990, 1991, 1992) investigated automatic processing development with spatial pattern information. One of these experiments (Eggemeier et al., 1992) involved applying the NASA TLX procedure to examine the subjective workload associated with CM and VM performance with complex spatial pattern information in a memory/visual search task. This experiment had the additional objective of evaluating the effects of memory load variations on workload under CM and VM conditions. Memory set size, varied at two or four patterns, represented a within-subjects manipulation. Mapping condition was a between-subjects variable. The performance results of this experiment, described in Section II, support some level of automatic processing development within the

CM condition. CM performance was more rapid than VM performance across 8000 acquisition trials and showed a marked attenuation of the memory set size effect on both reaction time and accuracy.

Overall, TLX workload ratings declined as a function of training in both mapping conditions. Although there was no main effect of mapping condition on rated workload, memory set size significantly affected workload ratings within the VM but not the CM condition. Higher workload ratings were associated with increased memory load in the former condition. Therefore, the workload associated with the CM condition was unaffected by differences in demand levels within the memory/visual search task, while VM workload reflected these differences. These results are consistent with those of Vidulich and Pandit (1986), who reported an attenuation of memory set size effects on rated workload under CM versus VM conditions within a semantic memory search paradigm. Vidulich and Pandit (1986) also failed to demonstrate a main effect of mapping condition on rated workload.

Secondary Task Assessment of Workload Under Consistently Mapped and Variably Mapped Conditions

An important potential benefit of workload reductions concerns the allocation of processing resources not required for an automatized task component to concurrent tasks. Allocation of these resources to concurrent tasks could improve the operator's ability to perform such tasks, thereby increasing timesharing performance. The expected increases in timesharing levels with automatic processing have been demonstrated in a number of instances (e.g., Fisk and Lloyd, 1988; Fisk and Schneider, 1983; Schneider and Fisk, 1982a, 1984; Strayer and Kramer, 1990; Venturino, 1991) in which CM tasks have been performed at high levels with concurrent VM tasks.

The rule-based search task experiment described in the previous section demonstrated significant workload differences associated with CM and VM performance. The previously described spatial pattern experiment showed that increases in memory set size within a memory/visual search task that required the processing of spatial pattern information were associated with increased subjective workload ratings under VM but not CM conditions. Therefore, the results of both experiments were consistent with a reduction in the workload associated with the automatic processing of information intended to represent C^2 system materials.

Although both experiments demonstrated reduced subjective workload levels in memory/visual search tasks, neither experiment directly addressed reductions in processing resources through application of a performance-based secondary task workload assessment technique. Consequently, an additional experiment was conducted to assess the workload imposed by CM and VM memory/visual search as indexed by secondary task methodology.

Secondary task methodology (e.g., Eggemeier and Wilson, 1991; O'Donnell and Eggemeier, 1986) requires the concurrent performance of a primary task and a secondary task. The primary task is of principal interest; a secondary task is added to gain an index of the workload associated with primary task performance. The basic rationale of secondary task methodology is that primary tasks that require high levels of resource/capacity expenditure will afford less additional capacity for secondary task performance. Consequently, such primary tasks will result in poorer levels of concurrent or dual-task performance than will those that require lower levels of resource/capacity expenditure.

Two major secondary task paradigms can be applied to assess operator workload: (1) the subsidiary task paradigm, and (2) the loading task paradigm (e.g., Knowles, 1963; O'Donnell and

Eggemeier, 1986). Both paradigms are designed to assess primary task workload but differ in the emphasis placed on primary or secondary task performance under dual-task conditions. Applications of the subsidiary task paradigm emphasize primary task performance maintenance at single-task levels with the assumption that the secondary task performance level will provide an index of the amount of resource/capacity expenditure associated with the primary task. Applications of the loading task paradigm, on the other hand, emphasize secondary task performance maintenance at single-task levels under concurrent-task conditions. The secondary task in this paradigm imposes additional loading on the primary task, with the intent of simulating the processing load associated with other tasks or operator functions performed within an operational environment. Within this paradigm, primary task performance decrements incurred under dual-task conditions represent the measure of primary task workload. The loading task paradigm assumes that tasks that require a high level of capacity/resource expenditure will show larger decrements with the addition of the secondary task than will primary tasks that require lower levels of capacity expenditure. Because this paradigm simulates the demands of additional system functions or tasks and requires emphasis of secondary task performance under dual-task conditions, the loading task paradigm was used.

Subjects performed two memory/visual search tasks under both single-task and dual-task conditions. The primary task was the same as the one used in a previously described experiment (Eggemeier et al., 1992) that evaluated the subjective workload associated with processing complex spatial pattern information under CM and VM conditions. The secondary task procedure was identical to that of the primary task but required that different static spatial patterns be stored in memory and searched on test displays. The primary task was presented under either CM or VM conditions. The secondary task was always performed under VM conditions.

The single-task performance procedure for both the primary and secondary tasks included presentation of the memory set followed by ten probe items that consisted of two spatial patterns. Subjects indicated the position of the memory set item through a key-press response. Memory set size was varied at either two or four items in both tasks. The dual-task performance procedure was the same as that used under single-task conditions with the exception that memory sets and probes, for both the primary and secondary tasks, were presented within each block of trials. Test probes for the primary and secondary tasks alternated in a series. Prior to the dual-task phase of the experiment, subjects had completed 1920 practice trials on the secondary task and 8640 practice trials on the primary task. During the dual-task phase of the experiment, subjects completed 1920 dual-task trials and 1920 single-task baseline trials.

CM primary task reaction time performance was relatively unaffected by both the addition of the secondary task and manipulations of its memory load levels. VM reaction time, on the other hand, showed a more substantial decrement with the addition of the secondary task than did CM performance and was also more markedly affected by the increase in secondary task demand levels. There also was some attenuation of the secondary task demand level effect on primary task reaction time as sessions progressed. Introduction of the secondary task was accompanied by slight accuracy increases within the CM condition and by some accuracy decreases within the VM condition. The VM decrements were most pronounced at the high level of secondary task demand.

Decrements in secondary task reaction time performance occurred between the single-task baseline and dual-task conditions in both the CM and VM groups. However, the magnitude of the decrement effect was greater in the VM versus the CM group. Also, while the VM group demonstrated a significant

decrement within dual-task performance as a function of the increase in primary task demand levels, the CM group showed no such decrement. Finally, the accuracy of secondary task performance did not vary as a function of primary task mapping condition.

The overall pattern of primary and secondary task results indicated that the workload associated with a CM version of a spatial pattern memory search task was lower than that associated with a VM version. Thus, the results of this experiment confirm the workload reductions that can be associated with automatic processing of spatial pattern information of the type incorporated into some C² systems. The data also extend previous dual-task results reported with alphanumeric and semantic information (e.g., Fisk and Schneider, 1983; Schneider and Fisk, 1982a, 1984; Strayer and Kramer, 1990) and other forms of spatial information (e.g., Fisk and Lloyd, 1988; Venturino, 1991) to static spatial pattern information intended to represent that processed by C² system operators.

Summary and Discussion

The results of each experiment (Eggemeier et al., 1992) that employed subjective measures to assess the workload associated with CM and VM performance were consistent in demonstrating some workload advantage of the CM versus the VM condition. The lower workload associated with CM performance, demonstrated in the complex alphanumeric experiment, is of considerable potential importance to C² operators who must process large volumes of information under some conditions. Lower workload levels can be associated with improved timesharing efficiency; therefore, the present results are potentially significant for performance levels that could be achieved by C² operators under high workload timesharing conditions. Previous work (Reid, Shingledecker, and Eggemeier, 1981), for example, demonstrated a high correlation between rated workload and the capability of subjects to perform

a concurrent secondary task. If this relationship were to hold true with alphanumeric information in memory/visual search, the lower workload ratings would indicate that CM versions of the rule-based task could be timeshared more effectively with an additional task than VM versions.

Failure to find overall differences in subjective workload under CM and VM conditions in the spatial pattern search experiment (Eggemeier et al., 1992) is consistent with the previous results of Vidulich and Pandit (1986). These data contrast those of the complex alphanumeric rule-based experiment noted above, and with those of Vidulich and Wickens (1986) and Vidulich and Pandit (1987), who examined the workload associated with memory and memory/visual search for letters. However, both the Vidulich and Pandit (1986) and the present spatial pattern experiment demonstrated more pronounced workload effects of memory set size variations within the VM versus the CM condition.

Causes of the apparent inconsistencies in results cannot be precisely identified on the basis of the present data. However, one possible cause concerns the design of the respective experiments. The spatial pattern experiment (Eggemeier et al., 1992) discussed here and the Vidulich and Pandit (1986) experiment incorporated mapping condition as a between-subjects variable and memory set size as a within-subjects variable. In contrast, the present alphanumeric rule-based training experiment (Eggemeier et al., 1992) and both the Vidulich and Wickens (1986) and Vidulich and Pandit (1987) work employed a within-subjects design to examine mapping condition effects on subjective workload. This difference in the type of mapping manipulation may represent a critical factor in the noted results. Subjects in the rule-based experiment and in the Vidulich and Wickens (1986) and Vidulich and Pandit (1987) work experienced both CM and VM conditions, whereas subjects in the spatial pattern and Vidulich and Pandit (1986) experiments did not. Therefore, it is possible that differences in mapping condition anchor points

under the between-subjects versus the within-subjects designs could have influenced the sensitivity of subjective ratings to overall CM-VM workload differences. The rated workload differences associated with memory set manipulations, in both the spatial pattern and Vidulich and Pandit (1986) experiments, are consistent with this hypothesis. Nonetheless, both the present rule-based and spatial pattern training experiments (Eggemeier et al., 1992) provided evidence of some workload differences between CM and VM conditions.

The same type of CM versus VM workload advantage demonstrated during the rule-based alphanumeric task acquisition experiment continued to be demonstrated in both the transfer and retention experiments employing the same materials. These results are potentially significant to operator workload within complex systems because they indicate that the lower workload levels associated with the CM condition persist under both the transfer and retention conditions tested. However, the significant rated workload increase that occurred under both mapping conditions over the one-month retention interval is also of potential importance because the workload imposed by a task can affect critical elements of operator performance, such as timesharing capability.

The results of the final experiment (Eggemeier et al., 1992) confirmed the workload reductions expected after extensive CM training with complex spatial pattern information through application of a secondary loading task paradigm. These findings are significant because workload reductions and the capability to maintain performance of CM task elements under additional processing load constitutes a principal rationale for automatic processing development within complex C^2 system task components.

Future research of importance to eventual automatic processing applications to C^2 operator training should apply secondary task methodology to investigate the workload associated

with the processing of dynamic spatial pattern information and with performance of rule-based alphanumeric memory/visual search tasks investigated in other elements of this program. An additional issue for future research is secondary task assessment of the workload associated with task performance over the types of retention intervals investigated in the previous series of experiments. One experiment in this series demonstrated increases in subjective workload within a rule-based alphanumeric search task over a one-month interval. An important issue not addressed by that experiment concerns the implication of any such workload increases with respect to the timesharing efficiency exhibited under the type of dual-task conditions evaluated here. Workload increases could possibly compromise dual-task performance efficiency under conditions in which primary task performance remained relatively stable. Therefore, dual-task performance efficiency constitutes an additional criterion that should be applied in future evaluations of the effects of retention intervals on performance under CM and VM conditions.

VI. PROCESSING PRINCIPLES AND TRAINING GUIDELINES

Existing Processing Principles and Training Guidelines

One important outcome of the research described above is the opportunity to refine existing principles of operator information processing and guidelines for training that are related to the characteristics and development of automatic processing. Such processing principles illustrate human performance characteristics that have proven important for knowledge engineering to enable the understanding of operational tasks and development of training programs for high performance skills of the type found in Air Force C² systems. General principles, which were based on research conducted prior to the work

discussed above, are well-described by Fisk et al. (1987). Those existing principles of human performance and training guidelines can be summarized as follows.

- Performance improvements will occur only for situations in which stimuli or information can be dealt with the same way from trial to trial.
- The human operator is limited not by the number of mental operations required but by the number of inconsistent or novel cognitive or psychomotor operations required.
- Consistent task components must be identified and then trained to levels of automaticity in order to alleviate high workload situations.
- Training should be conducted to develop automatic task components in order to make performance reliable under environmental stressors (e.g., alcohol, fatigue, heat, noise).
- For tasks requiring sustained attention (i.e., vigilance), automatic target detection should be developed prior to participation in the vigilance task. Also, VM information should not be presented in a continual and redundant pattern.
- When preparing training programs, instructional designers should consider the nature of the underlying processing modes (i.e., automatic or controlled) when choosing part-task training strategies.

Augmented Processing Principles and Training Guidelines

The research discussed throughout this final report, as well as additional data in the current literature, provide an empirical basis for augmenting these performance principles and training guidelines. The adopted approach has been not only to specify the boundary conditions under which the principles of consistency operate but also to demonstrate situations in which consistency may be mimicked through context or may even be detrimental in transfer situations. A summary of the augmented processing principles and training guidelines, gleaned from data presented in this report and the current literature, is provided below. The augmented principles and training guidelines are organized according to the major aspects of performance or training described.

Higher-Order, Rule-Based Consistency

- The consistency necessary for performance improvement and automatic processing development need not be related to the individual stimulus level. This principle is very important for training applications to complex C^2 skills because it is likely that many consistencies within such skills will be at higher-order or rule-based levels. Consistent relationships among stimuli, rules, and context should be identified when considering part-task training strategies.

Contextually Defined Consistency

- Context can affect operator performance in two major ways. First, contextual cues may be used to bias performance and mimic the effects of consistency. However, performance in this situation remains resource-sensitive. Second, contextual cues may

activate automatic sequences of behavior and context activation follows lawful temporal development.

Degree of Task or Component Consistency

- Performance improvements will occur only for consistent elements of a task or skill, and the degree of improvement is directly related to the degree of consistency. This direct relationship between consistency and performance applies not only to search functions investigated in earlier work but also to search functions that approach the perceptual limit of individual subjects. The noted relationship is central to the development of training programs for complex skills (such as those found in C^2 systems) because it is unlikely that completely consistent task components will be found in all instances. This relationship indicates that task components demonstrating less-than-perfect consistency can be effectively incorporated into training programs. The relationship further suggests that methods (e.g., Eggemeier et al., 1988; Fisk and Eggemeier, 1988) of consistent task component identification for incorporation into training programs should be structured to permit identification of task components that exhibit less-than-perfect consistency.

- Operator performance is limited by the number of inconsistent cognitive operations. However, performance may also be limited by the type of search task structure, as illustrated by the data reviewed above concerning pure memory versus pure visual versus hybrid visual/memory search. Limits associated with operator performance which are imposed by different search tasks are potentially important to skilled performance within C^2 systems that can incorporate each of the noted search functions.

- Global consistency within a task can dominate performance improvement if lower-level consistency is absent. This principle indicates that instructional system designers should identify and fully analyze such global consistencies within complex tasks so that training programs can be designed to capitalize on the performance improvements associated with such consistencies. Once again, this principle is of considerable potential importance for the type of complex tasks that typify the C^2 environment. It suggests that task analytic procedures (e.g., Eggemeier et al., 1988; Fisk and Eggemeier, 1988) that have been applied to identify consistent components of such tasks should be modified to incorporate methods for identification and analysis of such consistencies.

- Performance improvement occurs for lower-level, stimulus-based consistencies regardless of higher-order inconsistency. However, learning at the higher-order relational level is greatly attenuated by any degree of global inconsistency. This principle is of considerable potential importance for analysis of the types of complex operator tasks within C^2 systems expected to incorporate such consistency levels. Once again, the principle suggests the necessity of incorporating techniques in order to identify such consistencies within task analytic methodologies and structure training programs to capitalize on varying consistency levels.

Benefits of Consistency as a Function of Amount of Practice

- A direct relationship exists between amount of consistent practice and stimulus activation strength. However, this functional relationship may be superseded

by other variables. For example, the opportunity to form a superset of the memory-set elements or general task training to improve the motor components of the task may mask the performance benefits of stimulus activation strength.

Transfer of CM Tasks or Task Components

- Disruption at transfer due to task component recombination of automatized task components is directly related to the priority strength of competing components.
- The effect of physical features changes in to-be-processed information upon CM performance appear to be dependent upon the type of search function required and possibly upon the type of information to be processed. Changes in the physical characteristics of semantic and alphanumeric information under memory search conditions produce relatively minor effects compared to changes in the to-be-processed information itself. Manipulations of spatial pattern orientation under visual/memory search conditions initially reduce CM performance to VM levels.
- Some performance benefits of CM training transfer to untrained exemplars of trained semantic categories and trained alphanumeric rules. Such transfer is of potential importance to the design of training programs intended to support automatic processing development within rule-based or category-based consistent components. Training programs can be structured to take advantage of the transfer to such untrained exemplars.

Facilitation of Consistent Component Skill Acquisition

- Part-task training can result in efficient associative learning, at least for semantic-based processing. Acquisition of skilled search performance with both semantic and spatial pattern information is not negatively affected by simplification variants of part-task training. Target strengthening (priority learning) benefits most from part-task training, as illustrated by retention functions that assess target as opposed to combined target/distractor learning within a search task.
- Target prompting implemented through the manipulation of visual target or background noise intensity facilitates prompted performance within complex spatial pattern search but has not yet been shown to transfer to unprompted performance. Target prompting may provide a means of increasing the number of training trials completed by trainees early in practice and has not shown negative effects in transfer to nonprompted conditions.

Retention of Performance with Consistent Components

- Long-term retention of automatized task components that require the processing of semantic, alphanumeric, and spatial pattern information is related to the type of task-specific processing. Memory access shows no decay for periods ranging from one month to one year. Visual search shows statistically nonsignificant decay after one year. Maximum decay, related to the coordination of component information that characterizes visual/memory search paradigms, does not appear to be related to component activation.

Workload Associated with Different Mapping Conditions

- Differences exist in the subjective workload associated with CM and VM search task performance. Consistent conditions exhibit an advantage in either overall rated workload or in the effect of memory set demand manipulations. The capability to timeshare or perform a concurrent secondary task is superior under CM versus VM conditions with a variety of materials, including alphanumeric, semantic category, and spatial pattern information.

As reflected in these augmented principles of processing and associated training guidelines, the results of this research program have provided information that is important to the development of a refined methodology for structuring training programs that will support the acquisition, transfer, and retention of automatic processing in consistent components of C² operator tasks. The principles and guidelines presented here should contribute to eventual application of an automatic-processing-based approach to high-performance skill development for C² system operators.

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APPENDIX A: ACRONYMS

<u>Acronym</u>	<u>Definition</u>
C ²	Command and Control
CM	Consistently Mapped
CRT	Cathode Ray Tube
D/D	Different Rules, Different Exemplars
NASA	National Aeronautics and Space Administration
PT2	Part-task Training of Two Semantic Categories
PT3	Part-task Training of Three Semantic Categories
S/D	Same Rules, Different Exemplars
TLX	Task Load Index
VM	Variably Mapped
WT6	Whole-task Training of Six Semantic Categories